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EXAMINATION OF THERMAL IMPACTS FROM STORMWATER BMPS

BY

NICHOLAS P. DIGENNARO
B.S., Rochester Institute of Technology, 2008

THESIS

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Master of Science
in
Civil Engineering

May, 2010

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ABSTRACT

EXAMINATION OF THERMAL IMPACTS FROM STORMWATER BMPS

by

Nicholas DiGennaro

University of New Hampshire, May, 2010

This study presents the examination of 4 years of monitoring of runoff temperature for a range of stormwater best management practices (BMPs) in relation to established environmental indicators for a study in Durham, NH. Stormwater BMPs examined include conventional, Low Impact Development, and manufactured treatment designs. Surface systems that are exposed to direct sunlight have been shown to increase already elevated summer runoff temperatures, while other systems that provide treatment by infiltration and filtration can moderate runoff temperatures by thermal exchange with cool subsurface materials. The storm sewer system saw an annual average event mean temperature (EMT) greater than the mean groundwater temperature of 47°F that commonly feeds coldwater streams (Heath, 1983). The examination of BMPs indicates that outflow from the larger surface systems exhibit greater thermal variations and the larger subsurface systems exhibit greater thermal buffering, with outflows consistently nearly equivalent to groundwater temperatures.

CHAPTER 1

EXAMINATION OF THERMAL IMPACTS FROM STORMWATER BMPS

1.1 - Introduction

As urban areas continue to grow, the temperature effects expand along with them. The "heat island effect" occurs around urban areas with large, dark impervious surfaces. Urban heat islands are considered an issue primarily in the south, but several urban heat island mitigation efforts have taken place in the northeast and other cooler climates in the United States[1]. The increase in thermal energy in stormwater runoff is primarily from the increasing impervious areas of the surrounding area. Many of the same elements that create the heat island are found in the causes for increased stormwater runoff temperatures. The impervious surfaces absorb and give off heat creating air and surface temperatures that are significantly higher than those of rural areas (Arya 2001). An increase in urban areas creates more impervious surfaces (commonly as high as 80-90% impervious cover in a developed urban area) resulting in additional surface runoff. The combination of these two phenomena creates a larger volume of runoff with increased temperatures. Impervious surfaces include building rooftops, roads, parking lots, and sidewalks. Impervious surfaces can be generalized as any constructed surface that inhibits the infiltration of stormwater runoff (Kieser et al. 2003). The darker the impervious surface (asphalt, some roofing materials), when compared to a natural

[1] The EPA provides a list of states with initiatives to mitigate the heat island effects within and around the city of concern. (http://www.epa.gov/heatisland/)

surface, the greater the heat adsorption from solar radiation. The ratio of the amount of solar radiation reflected from a surface to the total solar radiation received by the surface is referred to as the albedo, or solar reflectance of the material. Darker surfaces tend to have low solar reflectance, as the material has absorbed most of the solar radiation. Fresh asphalt for example, has a solar reflectance value of 0.05. A lighter surface, like fresh, white Portland cement concrete, has an average solar reflectance of 0.75 (PCA, 2010). The surface runoff removes the heat absorbed by the darker impervious surfaces as it flows across the surface. This heated runoff flows into the receiving stream, where it mixes, and potentially increases the temperature of the stream. The amount of heat transferred, and the degree of thermal pollution is of great importance for fisheries management. Coldwater fisheries in particular are sensitive to thermal pollution.

1.2 - Background

Stormwater Best Management Practices (BMPs) have been primarily used to reduce the peak flow of the stormwater runoff rate by some means of storage. Heat is considered a pollutant under Section 502(6) of the Clean Water Act. The increased summer temperatures of stormwater runoff may have a large impact on streams and cold-water fisheries. The increase in impervious cover of a watershed was used as a measure of pollutants entering a stream and its watershed in a study of the Eagleville Brook watershed in Mannsfield, Connecticut. One of the potential causes for the impaired stream identified in this study was the elevated stream temperature. The potential source of these elevated stream temperatures was reported to be from the increased impervious surfaces (CTDEP, 2007). The Energy Independence and Security Act of 2007 (EISA) requires all federally funded building projects greater than 5,000 square feet to recreate predevelopment hydrologic conditions, including temperature. Temperature is a very important factor in the chemical and biological processes of organisms (Roa Espinosa et al. 2003). Certain biological activities, such as reproduction and spawning of organisms may be very sensitive to changes in temperature.

This research is based on the concept that the greater the heat capacity of a system, the greater the capability of exchange of thermal energy.

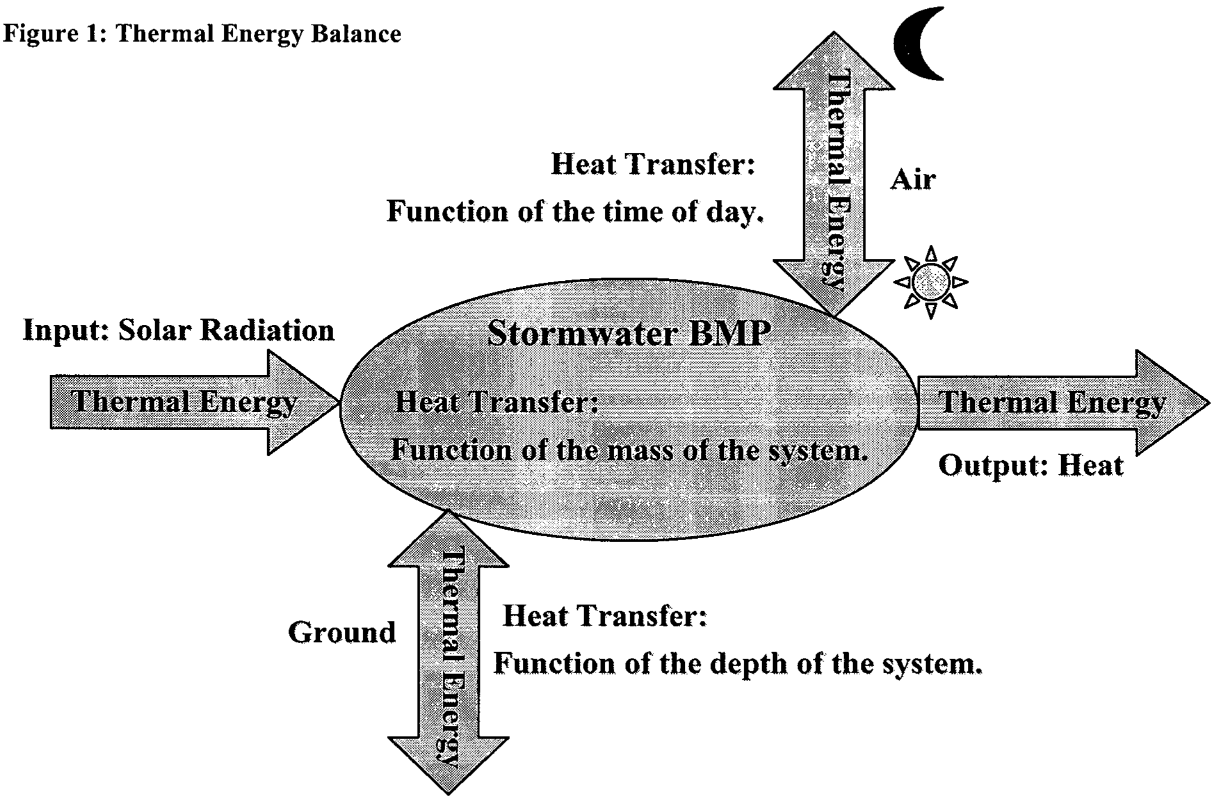
Equation 1: Heat Capacity

$$C_{th} = m*c_p$$

C_{th} = heat capacity (J/^{o}C)
m = mass of the system (kg)
c_p = specific heat capacity (J/kg^{o}C)

This research hypothesis is that heat and thermal variations are a function of size and the degree of surface exposure of the stormwater BMPs. It should follow that the larger surface systems will manifest greater thermal impacts because they are directly exposed to ambient air and solar variations. Outflow from subsurface systems should exhibit greater thermal buffering because of reduced exposure to air temperature variations and because they are insulated from the solar radiation from the ground around the system. The degree of influence of a system would be a function of size (heat capacity), exposure (heat transfer), and depth (heat insulation). The thermal energy balance is depicted in Figure 1 below. The input of thermal energy into the system is described as the available solar radiation. Then, within the stormwater BMP, the heat is dissipated or added depending on the system characteristics of depth and mass, and the exposure to the ambient air conditions. During the day, surface systems are expected to gain additional thermal energy, while at night, some of that thermal energy is dissipated into the cooler surrounding air. The net loss or gain of thermal energy is then released from the system. The resulting output of heat is then a function of available solar radiation, time of day, system mass, and system depth.

Figure 1: Thermal Energy Balance



1.3 - Literature Review

Summer stormwater runoff temperature has increased because of the increase in urban impervious surfaces and in the unshaded ponds and channels that characterize conventional stormwater BMP systems (Kieser et al. 2003). In many cases, the temperature of the stormwater runoff is increased twice before it even has the chance to cool down before it enters the receiving waters. The temperature of the stormwater is increased first by contact with impervious surfaces, and then again, in the stormwater ponds that hold the stormwater being treated. Kieser, et al (2003) reported temperature equivalent values of 74°F coming off a 79 acre site in Portage Michigan. This was 40°F higher than the average air temperature recorded in the study.

Coldwater ecosystems are susceptible to impacts caused by the increase in stormwater runoff temperatures during the summer months. The narrow temperature margin at which the coldwater aquatic life can thrive limits the ability of the coldwater ecosystem to assimilate these increases of temperatures. Generally, three temperature indices are considered for coldwater ecosystems. The lower optimum level is around 45 degrees Fahrenheit, the upper optimum level is around 65 degrees Fahrenheit, and the lethal limit for most coldwater aquatic species hovers just below 80 degrees Fahrenheit (Dorava et al. 2003). The range between the upper optimum limit and the lower optimum limit is sometimes referred to as the 'optimum zone' where coldwater aquatic life tends to thrive. The next zone, commonly known as the 'stress zone', is between the upper optimum limit and the lethal limit. The longer the fish and other aquatic life remain in the stream water that has reached this temperature range, the more likely the fish will become stressed. The coldwater species inhabiting the stream will generally move away from areas in the stream that have reached the 'stress zone', if the lethal limit is reached, the fish will die, or they will simply not move into that area. However, the entire thermal regime should be considered when the health of the stream ecosystem is monitored. The natural thermal regime of a stream has a range and frequency of the seasonal highs and lows, and plays an important role in the survival, and reproduction, of the aquatic life within the stream. The day-to-day changes in stream temperature play a vital role in the activity of the aquatic life. The natural differences play a vital role in the activity of coldwater species for migration and reproduction (Macri 2006). It may be less important to maintain a constant outflow temperature for a stormwater BMP, than to maintain the natural balance of temperature and flow that meets the natural thermal regime of the receiving waters. Another factor associated with temperature, and the health of the coldwater species, is the relationship between temperature and dissolved oxygen (DO). As the temperature of the water increases, the amount of DO decreases. DO is vital in the survival and continued growth of many coldwater species. Therefore, while the increase in temperature of the coldwater stream can be detrimental to the health of the stream itself, it also affects the amount of dissolved oxygen within that stream, affecting the health even further.

CHAPTER 2

SITE DESCRIPTION

The study site is located at the University of New Hampshire Stormwater Center (UNHSC) field facility. The data in this report reflects events monitored between 2004 and 2008. The UNHSC is located on the perimeter of a 9-acre (900 parking spaces) commuter parking lot at the University of New Hampshire (UNH) in Durham, NH. The parking lot, installed in 1996, is standard dense mix asphalt, curbed, and is used to near capacity throughout the academic year. Activity is a combination of passenger vehicles, and routine bus traffic. The time of concentration is 22 minutes from the most hydrological distant point at approximately 1,200 feet, with surface slopes varying between 1.5% and 2.5%. The stormwater runoff is collected into 16 catch basins and then routed through a system of reinforced concrete pipes (RCP) increasing in sizes as the flow moves downstream from 12" to 36". The 16 catch basins are placed approximately every 150 feet and are connected in-line with the downstream catch basins. At the head of the site, the flow is equally distributed to the eight BMPs connected in a parallel configuration to deliver "dirty stormwater" to each device. The site is designed to mitigate any significant transmission impacts such as sedimentation from the distribution system or routing of the hydrograph. The treated stormwater from each BMP is then fed by gravity to a sampling gallery where sampling and flow monitoring is performed (Roseen et al. 2006).

CHAPTER 3

SYSTEM DESCRIPTIONS

The following system descriptions describe generically each of the systems included in this study, followed, when possible, by the specific design characteristics of each system that are found at the UNHSC. The full descriptions of each system can be found in the biannual reports of the UNHSC[2].

The design volumes used in sizing stormwater BMPs include the water quality volume (WQv) which is equivalent to the runoff volume of one inch of rainfall over the drainage area. The channel protection volume (CPv), is equivalent to the runoff volume generated by the 2-year, 24-hour rainfall event, also referred to as the Q2. The third design volume, the conveyance protection volume, (Qp) is equivalent to the runoff volume generated by the 10-year, 24-hour rainfall event, and is often referred to as the Q10.

3.1 - Retention Pond

Retention ponds, or "wet ponds," are among the most common stormwater treatment systems used today. They are not to be confused with detention basins or "dry basins," which hold runoff for a specified period, and then release the entire volume of the runoff. Retention ponds retain a resident pool of standing water, intended to improve

[2] UNHSC 2005 Biannual Report http://www.unh.edu/erg/cstev/pubs_specs_info/annual_data_report_06.pdf
UNHSC 2007 Biannual Report http://www.unh.edu/erg/cstev/2007_stormwater_annual_report.pdf
UNHSC 2009 Biannual Report http://www.unh.edu/erg/cstev/pubs_specs_info/2009_unhsc_report.pdf

water quality between storms. Retention ponds demonstrate a reasonably strong water quality treatment, particularly in comparison to dry pond systems, which is consistent with the findings of the EPA's 1993 National Urban Runoff Program (NURP) studies. However, lack of maintenance often leads to reduced treatment performance and gradual erosion within the system for large flows.

The retention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to hold a resident pool of water. It was installed below the water table and thereby maintains a permanent pool of water. The clay soil, effectively acts as a lining for the system. Side slopes were stabilized with grass and spillways with stone and geotextile.

In general, retention ponds can be designed either above or below the groundwater table. Ponds are commonly designed for both aesthetic and habitat function.

The system is designed to treat the water quality volume (WQv), and the channel protection volumes (CPv) are conveyed through the system within 24 to 48 hours. During conveyance protection volume (Qp) rain events, stormwater is conveyed through the system, and bypasses the water quality treatment process

3.2 - Detention Pond

Detention basins or "dry basins," hold runoff for a specified period of time, then release the entire volume of the runoff. Similarly, to the retention ponds, a lack of maintenance often leads to reduced treatment performance and gradual erosion within the system during large flows.

The detention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to the hold the water quality volume (WQv). It was installed in clay soil, which effectively acts as a lining for the system. Side slopes were stabilized with grass, and spillways with stone and geotextile.

Detention ponds are commonly designed for both aesthetic and habitat function. The detention pond at the UNHSC is a revision of the retention pond previously in place at the site.

The system is designed to treat the water quality volume. Channel protection volumes (CPv) are conveyed through the system within 24 to 48 hours. During conveyance protection volume (Qp) rain events, stormwater is conveyed through the system, and bypasses the water quality treatment process.

3.3 - Gravel Wetland

The subsurface gravel wetland is a recent innovation in Low Impact Development (LID) stormwater design. It approximates the look and function of a natural wetland, effectively removing sediments and other pollutants commonly found in runoff, while enhancing the visual appeal of the landscape. The subsurface wetland evaluated at UNHSC is a horizontal-flow filtration system that should not be confused with other surface flow stormwater wetlands that function more like ponds. Instead, it relies on a dense root mat, crushed stone, and a microbe rich environment to treat water quality. Like other filtration systems, it demonstrates a tremendous capacity to reduce peak flow and improve water quality.

This subsurface gravel wetland was designed by the UNHSC. Its rectangular footprint occupies 5,450 square feet and can accommodate runoff from up to one acre of impervious surface. It includes a pretreatment sedimentation forebay that preserves the filter media, followed by two flow-through treatment basins. (Other pretreatment approaches may be used.)

Each treatment basin is topped with eight inches of wetland soil. The clay soil, in which the subsurface gravel wetland was constructed, acts as a liner. The sides of the system were lined with geotextile to prevent the clay soil from invading the subsurface gravel wetland. Gravel wetlands depend on horizontal filtration; however, trenches to promote infiltration (downward flow) can be incorporated at the end of the system.

The subsurface gravel wetland is designed to retain and filter the water quality volume (WQv) retaining10 percent in the forebay and 45 percent in each treatment basin. It can detain a channel protection volume (CPv) of 4,600 cubic feet, and release it over 24 to 48 hours. The conveyance protection volume (Qp) is bypassed. For small, frequent storms, each treatment basin filters 100 percent of the influent it receives. For larger storms that do not exceed design volume, stormwater bypasses the first treatment basin and is processed by the second. When storms exceed the design volume, the first inch of rain (first flush) is treated, while the excess is routed to conveyance structures or receiving waters.

Since standing water of significant depth is not expected, except during heavy rains, the side slopes of the system are graded as flat as the constraints of the site would allow, facilitating maintenance. With the exception of the forebay, the wetland hosts a healthy, diverse mix of native wetland grasses, reeds, herbaceous plants, and shrubs.

3.4 - Bioretention

Bioretention systems are among the most common LID stormwater approaches. Runoff flows into landscaped depressions, where it ponds and infiltrates the soil. The engineered soil mix and vegetation provide water quality treatment and infiltration similar to undeveloped areas. The UNHSC has evaluated four such systems. The first initially displayed strong performance and then experienced hydraulic failure after ten months due to design flaws. In 2005, UNHSC installed the current bioretention system, a smaller, more affordable system that addressed these flaws, and thus far, demonstrates better infiltration and strong water quality treatment.

The bioretention system is comprised of a sedimentation forebay and a bioretention filtration basin. The basin is filled with a bioretention soil mix (BSM) 30 inches in thickness, and consisting of 60 percent sand, 20 percent woodchips, ten percent compost, and 10 percent native soil. The filtration basin is well vegetated. Vegetation was selected for flood and drought tolerance, the capacity for maximum ground cover, and aesthetics.

3.5 - Vegetated Swale

Vegetated, dry, wet, or stone-lined—stormwater swales are open, channel-like structures that are used to convey stormwater runoff. The vegetated swale evaluated at the UNHSC should not be confused with the more complex "water quality swales," or "bioswales," which are often designed with modified soils and sub drains. It is a trapezoidal channel designed for minimal slope and maximum permissible flow velocity. Its ability to remove pollutants is modest at best, and is vulnerable to large, high-velocity storm flows.

Swales are easy to design and build. They can be rock-lined or vegetated, broad or narrow, curving or linear, natural or engineered. Vegetated swales are generally designed with a trapezoidal or parabolic shape to accommodate large fluctuations in the flow of stormwater runoff and to maximize surface contact areas.

Dense vegetation is the key to a swale's stabilization and function, yet it is often not established until years after the construction is complete. This lag is common, and results from the fact that dense root mats may take up to three months to develop depending on the local growing season, a requirement that often is not accommodated by construction calendars.

Typically, state design criteria for all swales, including those that are vegetated, specifies slopes of less than one percent, and flow velocities of less than one foot per second for Qp and lower flows. Other common sizing criteria, such as water quality volume (WQv), channel protection volume (CPv), and conveyance protection volume (Qp), were not used in the design of this system at the UNHSC.

3.6 - Hydrodynamic Separators

Hydrodynamic separators (HDS) are small, flow-through devices that remove sediment, trap debris, and separate floating oils from runoff. UNHSC evaluated four HDS designs from 2004 through 2006: the VortSentry, the Continuous Deflection Separator (CDS), the V2B1, and the Aqua-Swirl. While their proprietary designs vary, they all primarily rely on swirl action and particle settling to remove pollutants.

The design and specification of HDS devices varies, and is performed by the manufacturer in accordance with local watershed conditions and target water quality treatment objectives. Often, these systems are designed to replace or retrofit existing catch basins.

Typically, HDS devices consist of a chamber that is configured for tangential flow, meaning that stormwater either enters the device through an eccentrically located inlet or to vanes that create a rotational flow to enhance particle settling. Many also contain a flow partition to minimize sediment re-suspension during times when flow rates exceed the design target.

Typically, HDS devices are equipped with a baffled outlet to remove floating debris, oil, and grease in stormwater runoff. To prevent the re-suspension of captured solids during times of high flow volume, some manufacturers have adapted HDS designs to include internal, online bypasses. When appropriate, these systems also can be outfitted with external, offline bypasses so that high flows can bypass the system completely.

3.7 - ADS Infiltration System

The subsurface Advanced Drainage Systems (ADS) Infiltration System has demonstrated a strong water quality treatment performance and a tremendous capacity to reduce peak flows. It should be noted that the design tested at the UNHSC is distinctive in its use of coarse sand for a reservoir base and filter course, a refinement that enhances its effectiveness in treating water quality.

The ADS Infiltration System is an infiltration unit (IU) that performs much like a leach field. The unit is made of high-density polyethylene (HDPE) pipe and is designed to bear loads consistent with those experienced by parking lots. The system manufacturer in accordance with local watershed conditions and target treatment objectives performs the design.

The IU consists of three, 40-foot sections of 48-inch diameter, perforated HDPE pipe, laid over an infiltration base composed of two feet of bank run gravel. The top and sides of the excavation are wrapped in non-woven geotextile to protect the system from the lateral migration of fine particles from the surrounding soil. The bottom of the treatment unit is not lined, to prevent premature clogging of the system from fines caught in the liner, carried by runoff.

Stormwater flows of one cubic foot per second (cfs) enter the IU. Flows exceeding one cfs flow directly into the IU. During channel protection volume (Q2) events, stormwater fills the IU, which typically drains over a 24- to 48- hour period. During ten-a year (Q10) event, stormwater fills the IU, and then discharges directly to the surface, largely bypassing treatment.

3.8 - StormTech Isolator Row

The StormTech Isolator Row is a manufactured system designed to provide subsurface water quality treatment and easy access for maintenance. It is typically used to remove pollution from runoff before it flows into unlined infiltration chambers designed for detention and water quantity control. The Isolator Row consists of a series of StormTech chambers installed over a layer of woven geotextile, which sits on a crushed stone infiltration bed surrounded with filter fabric. The bed is directly connected to an upstream manhole for maintenance access and large storm bypass.

The StormTech Isolator Row is designed to provide subsurface water quality treatment for small storms. The manufacturer adapts the system's design in accordance with local watershed conditions and target treatment objectives.

Chamber units are made of high-density polyethylene (HDPE) pipe and are designed to bear loads consistent with those experienced by parking lots. The UNHSC chamber dimensions are 51 x 30 x 85.4 inches (width x height x length) and are laid over woven geotextile, which rests on an infiltration base composed of one foot of three quarter inch crushed stone. The entire excavation is then wrapped in nonwoven geotextile to protect the system from the migration of fine particles from the surrounding soil.

Stormwater flows of up to one cubic foot per second (cfs) enter the system through an upstream manhole or other flow diverter. A bypass is incorporated in the StormTech system where flows exceeding the design rate are bypassed around the device and flow directly into adjacent chambers that can be sized to treat the CPv and Qp.

CHAPTER 4

MATERIALS AND METHODS

4.1 - Site Data Collection

Data has been collected at the UNHSC field research facility since 2004. Because systems are periodically changed, the length of record for each system ranges from 2 years and up. Real-time sample monitoring occurred at the entrance and exit of each BMP and was performed using a YSI Model 600XL multi-parameter sonde, recording pH, temperature, dissolved oxygen, and conductivity at 5 minute regular intervals. The real-time data for eight different BMPs include bioretention, tree filter, gravel wetland, swale, stormwater ponds, porous asphalt, hydrodynamic separators, and subsurface infiltration systems. This study focuses on a few selected systems, retention pond, detention pond, gravel wetland, bioretention, vegetated swale, hydrodynamic separators, and two subsurface infiltration units. All data has been collected in accordance with the site QAPP (UNHSC Roseen et al 2008).

4.2 - Data Analysis

A compilation of the data for this study was selected over 4 years (2005-2008), and has resulted in a database with over 40 million data points.

For this research, data selection was based upon the examination of the storm hydrograph; specifically hydrographs that were bounded by baseline flows. Data recorded during storm flows were selected because this research is focused on the effects of the temperature of stormwater runoff. On average, four base line flow data points were selected before and after each storm to avoid cutting the storm short. Base line flow was defined as the base flow of the system, or zero prior to the start of the storm. The start of the storm began at the first increase in flow and ended when the flow receded to the base line flow criteria. The storms selected were based off the storms that the UNHSC sampled for other water quality concerns, and the storm occurring at least 1.5 days after the site-sampled storm. For example, a storm was selected by the UNHSC for sampling, and further analysis, this storm would be called "Storm 1," the next UNHSC sampled storm would be called "Storm 2", but if a storm occurred at least 1.5 days after Storm 1, but ended 1.5 days before Storm 2, it would be called "Storm 1a". Therefore, in a perfect year, each Storm #, would be followed be a Storm #a. These storms were selected to describe the storms of any given year. The storms sampled by the UNHSC were chosen to further explain the water quality concerns of those storms, and the second set of storms, the storms following the site-sampled storms, were chosen to strengthen the data set. This method was chosen to make sure variability and randomness remained intact so as not to be biased towards large or small storms and was verified by performing statistical tests described in the following section. On average, the site-sampled storms and the storms immediately after had one and a half antecedent dry days (Table 20). Storm data was gathered by analysis of both hydrograph and tabular data sets. Additional data was selected if another storm occurred less than 1.5 days after the end of the previous storm. Nonzero data, which appear as gaps in the data, resulting from instrument malfunction, loss of power to the equipment, or other issues, was determined and eliminated before analyzing the datasets.

The flow-weighted temperature for each storm was calculated as the event mean temperature (EMT) (Deletic 1998, Kieser et al 2003). The event mean temperature is congruous to the event mean concentrations (EMCs) calculated for other stormwater pollutants, which are widely used in the performance monitoring of stormwater BMPs. EMTs were determined for approximately 24 storms for eight systems.

Equation 2: Event Mean Temperature

$$EMT = \frac{\int_{O}^{T} t(t)q(t)dt}{\int_{O}^{T} q(t)dt}$$

EMT = event mean temperature (^{o}F)
T = Flow Duration (min)
t(t) = Flow Temperature (^{o}F)
q(t) = Flow (gpm)

This research employed statistical methods consistent with data analysis by the International Stormwater BMP Database. Each BMP study in the Database contains a Detailed Statistical Analysis Report for each monitored parameter to provide guidance about the efficiency of the practice. The descriptive statistics used to represent this data include 1) cumulative distribution functions, 2) time series analysis, 3) quartile assessments of the EMTs, and 4) the frequency distributions of the real-time temperatures of the storms for each system. The cumulative distribution functions, time series analyses, and quartile assessments were used to describe the EMTs of each system, and to compare them to that of the runoff. The frequency distribution describes the real-time storm data, focusing on the temperatures recorded during each selected storm event. The cumulative distribution function describes the non-exceedance probabilities of a certain value to occur. For example, the runoff has a 69% probability of not exceeding an EMT of 60°F. A time series analysis of the data can show trends and seasonality of the data. Quartile assessment illustrates the population differences by use of spread, skewness, and potential outliers without performing an analysis of the normalcy of distribution. The frequency distribution is used to show the range and frequency of the real-time temperatures (non-flow weighted), and illustrates the seasonality of the temperatures. Other, non-statistical methods were also employed to analyze the thermal impacts of the stormwater BMPs. As mentioned before, the mean July temperature of coldwater streams is often used by regulatory agencies to determine the health of the stream. The mean July temperatures of each system analyzed were calculated using the real-time temperature data. The second non-statistical method used was the calculation of a thermal load from each stormwater BMP, for each storm. The calculation of the thermal loading for each system is described further on in this report. This metric is intended to be used as a design tool to determine the effluent requirements of the chosen stormwater BMP.

4.3 - Data Validation

Statistical analysis of the frequency of storms per month was completed to determine if the trend and distribution of the sample data set was consistent with the trend and distribution of the full data set.

To do this, the number of storms sampled in each month over the four-year period of study, were counted, and combined. For example, in January, there were seven storms sampled, over the course of the four-year period of study, one from 2005, and two each from 2006, 2007, and 2008. This summation of storm counts was completed for each month, and a distribution of storms over a 12-month period was created.

The full data set was created with the hourly precipitation data from the Kingman Farm NCDC/NOAA data set. The beginning and end of every storm was selected based upon the same criteria as the storms selected at the site, with roughly 1.5 days between rain events. As with the sample data set, the number of storms in each month over the course of the four-year period of study was summarized to create a distribution (Table 1).

Table 1: Monthly Distribution of Storm Events, Real and Analyzed

Month	Real Count		Normalized Count	
	Farm	Site	Farm	Site
January	30	7	0.10	0.06
February	22	8	0.07	0.07
March	21	13	0.07	0.11
April	21	11	0.07	0.09
May	23	7	0.08	0.06
June	26	9	0.09	0.08
July	29	8	0.10	0.07
August	25	7	0.08	0.06
September	22	16	0.07	0.13
October	24	13	0.08	0.11
November	25	11	0.08	0.09
December	28	10	0.09	0.08

The storm counts for each month are normalized for statistical analysis. The means and medians of the two data sets were too different for direct comparison. Normalizing the data sets by dividing the number of storms each month by the total number of storms, allows a dimensionless, normalized, comparison of the magnitudes without losing the integrity of the datasets.

After normalizing the datasets, a two-sample Kolmogorov-Smirnov test (KS test) was done to determine if the two distributions were different from one another. The null hypothesis of these tests was that the two datasets came from the same distribution. Using the Dataplot™ software provided by the National Institute of Standards and Technology (NIST), the KS test accepted the null hypothesis. Therefore, the distribution of the storms selected for this research, was the same as the distribution of all the naturally occurring storms from 2004 through 2008.

NIST-Dataplot™ 2-SampleKolmogorov-Smirnov Test

Null Hypothesis H_0: Two samples come from the same (unspecified) distribution.
Alternate Hypothesis H_A: Two samples come from different distributions

Sample:
Number of Observations for Sample 1 = 12
Number of Observations for Sample 2 = 12

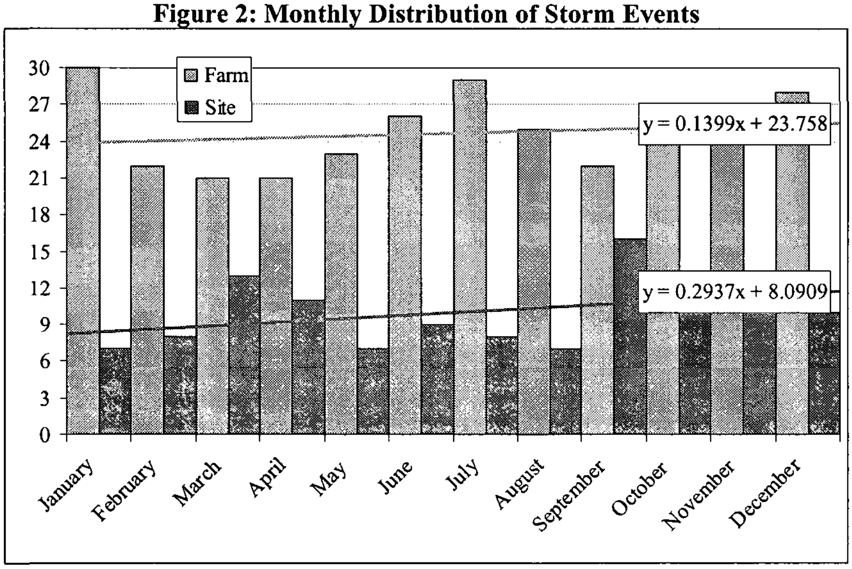
Test: Kolmogorov-Smirnov Test Statistic; D = 0.25

Table 2: KS Test Conclusions

Alpha Level	Cutoff	Conclusion
10%	0.41667	Accept H_0
5%	0.50000	Accept H_0
1%	0.58333	Accept H_0

A Student's T-test was performed to determine if the trends of the two datasets were different from one another. The null hypothesis was that the slope for the FARM dataset is the same as the slope for the SITE dataset. The slopes of the distributions represent the trend of the number of storms over the course of the years.

Figure 2: Monthly Distribution of Storm Events



A regression analysis was performed for each dataset, resulting in some basic statistics, including the Standard Error of the slope.

Table 3: Bivariate Analysis Summary

Term	Estimate	Std Error	t Ratio	Prob>|t|
SITE	0.2937063	0.236028	1.24	0.2417
FARM	0.1398601	0.266903	0.52	0.6117

Calculating the t-statistic: $t = \dfrac{b_1 - b_2}{s_{b_1-b_2}}$ $\quad s_{b_1-b_2} = \sqrt{s_{b_1}^2 + s_{b_2}^2}$

b_1 = slope of SITE data = 0.2937
b_2 = slope of FARM data = 0.1399

$s_{b_1-b_2}$ = standard error of the difference between the slopes

s_{b_1} = standard error of SITE slope
s_{b_2} = standard error of FARM slope

H_0: $b_1 = b_2$
H_A: $b_1 \neq b_2$ $\quad t = 0.43166$

Table 4: T-Test Conclusions

Alpha Level	Cutoff	Conclusion
10%	1.796	Accept H_0
5%	2.201	Accept H_0
1%	3.106	Accept H_0

After completing the t-test on the slopes, or trends, of the distributions, it can be concluded that the slope of the distribution of the storms selected each month for this research, was the same as the slope of the distribution of the storms naturally occurring from 2005 through 2008.

CHAPTER 5

RESULTS AND DISCUSSION

Effluent event mean temperatures for eight stormwater best management practices were compared to the event mean temperatures from a stormwater distribution system of the storms from 2004 through 2008. The influent flow and temperature data was measured at a common point to all of the stormwater BMPs (Runoff). The effluents of three distinctly different types of stormwater BMPs were analyzed, conventional systems (consisting of Detention Pond, Retention Pond, and Vegetated Swale); low impact development systems (consisting of Gravel Wetland, and Bioretention); and manufactured devices (consisting of Hydrodynamic Separators, ADS Infiltration System, and StormTech Isolator Row).

The data, when applicable, is presented in two ways. First, an annual summary of the data analysis is discussed to illustrate the system in its entirety. This type of analysis is useful when determining the average annual effect the system has on the thermal energy of the stormwater. However, this analysis is not able to demonstrate the effectiveness of the stormwater BMPs during the seasons. For example, the median and mean of the average annual EMT will be muted when compared to that of the summer months, and the opposite could be true during the winter months. This issue of seasonality of the data is discussed in the following sections. The seasons were chosen by dividing the year into two equal sections. The summer months are the six months in the middle of the calendar year, April through September. While the winter months are chosen as the first three and the last three months of the year, October through March. The seasons are not chosen based on the warmest and coldest months, but chosen to divide evenly, the year into two separate seasons.

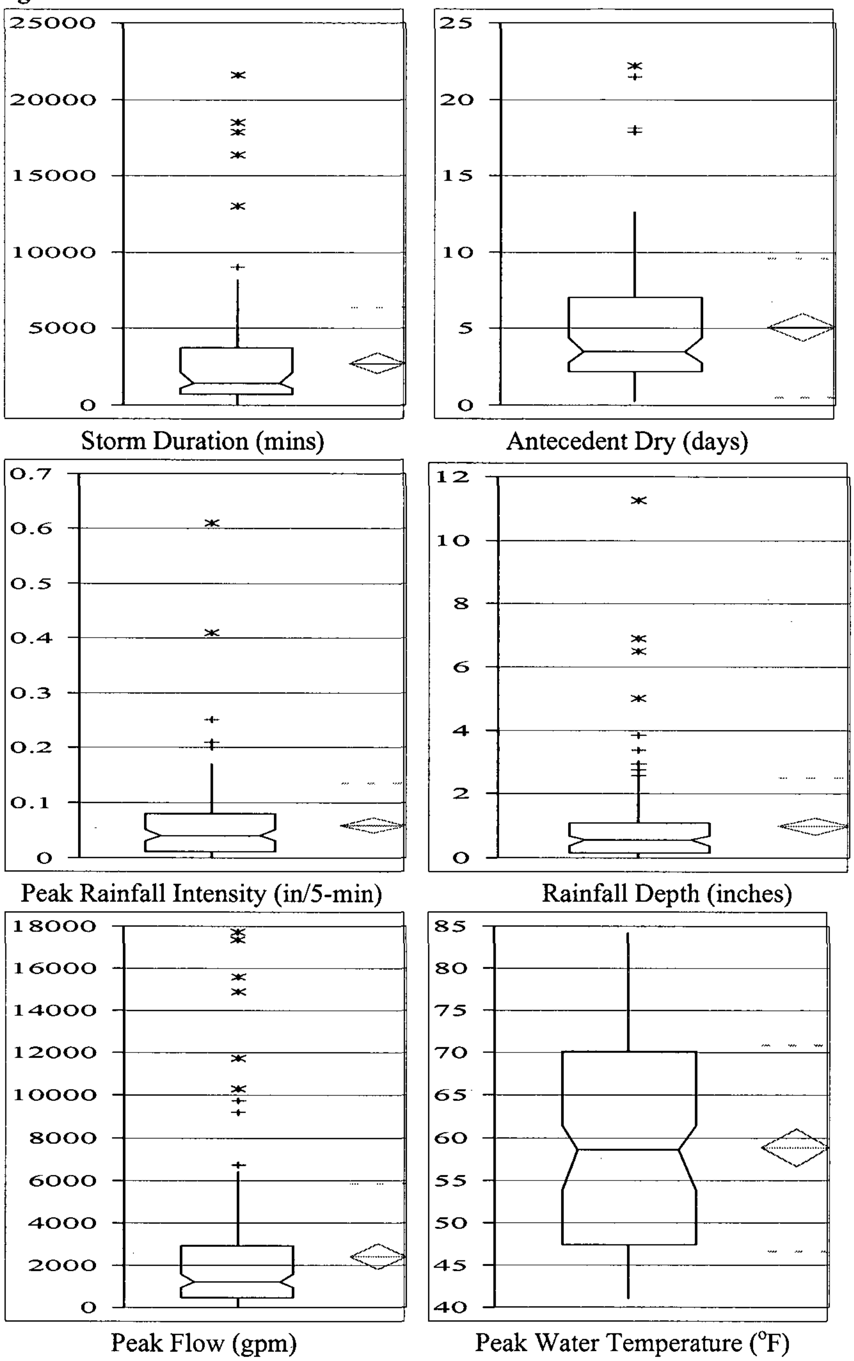
In addition to comparing the EMTs of each system to that of the runoff, the EMTs of the systems are compared to temperature data collected at several streams in the southeast region of New Hampshire. These streams include College Brook, Wednesday Hill Brook, and an upstream section of the Oyster River. The temperature data collected from each stream ranges in dates from December 2007 through January 2010. So while, this cannot be a direct comparison, because 1) it is a comparison of EMTs to real-time stream temperatures, and 2) the time of record differs for the streams and the stormwater BMPs, it can still be used as an indication of how the stormwater BMPs are performing with relation to these natural streams.

In Figure 3 below, the storm characteristics are described as a quartile assessment. The storm characteristics chosen were, storm duration, antecedent dry days, peak rainfall intensity, rainfall depth, peak flow, and peak water temperature of the runoff. A more detailed table of the storm characteristics can be found in Appendix A. A regression analysis was performed with ANOVA for four of the storm characteristics, storm duration, peak intensity, rainfall depth, and peak temperature. The analysis was done for the summer months, and then repeated for the winter months. The summer months, shown in Figure 4, identify the storm duration, rainfall depth, and peak temperature, as significant factors, individually, during the summer months. During the winter months, only the rainfall depth and the peak temperatures are individually, significant factors.

The storm duration is no longer a significant factor affecting the EMTs during the winter months.

Individually during the summer months, storm duration, rainfall depth, and peak temperatures are the most significant factors affecting the EMT of the runoff. However, when analyzed collectively, only the storm duration, and the peak temperature are significantly affecting the EMT of the runoff. During the winter months however, the same factors that are individually significant, are also collectively significant. During the winter, rainfall depth and peak temperature are the storm characteristics found to affect the EMT significantly (see Appendix D).

Figure 3: Distribution of Storm Characteristics for 120 Monitored Storms[3]



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[3] Storm Characteristic Key: the mean and 95% C.I. are shown as the diamond on the right hand side of each figure; the standard deviation about the mean is shown as the dashed lines above and below the mean diamond; outliers are shown as * or + above the quartile plot; maximum and minimum values are represented by the top and bottom of the vertical line centered on the quartile plot; the 25th and 75th percentiles are represented as the top and bottom of the quartile "box"; the upper and lower bounds of the 95% C.I. about the median is shown as the points of indentation in the quartile "box"; and the median is the horizontal line within the quartile "box" where the upper and lower bounds of the 95% C.I. about the mean intersect.

Figure 4: Summer Storm Characteristic Correlations

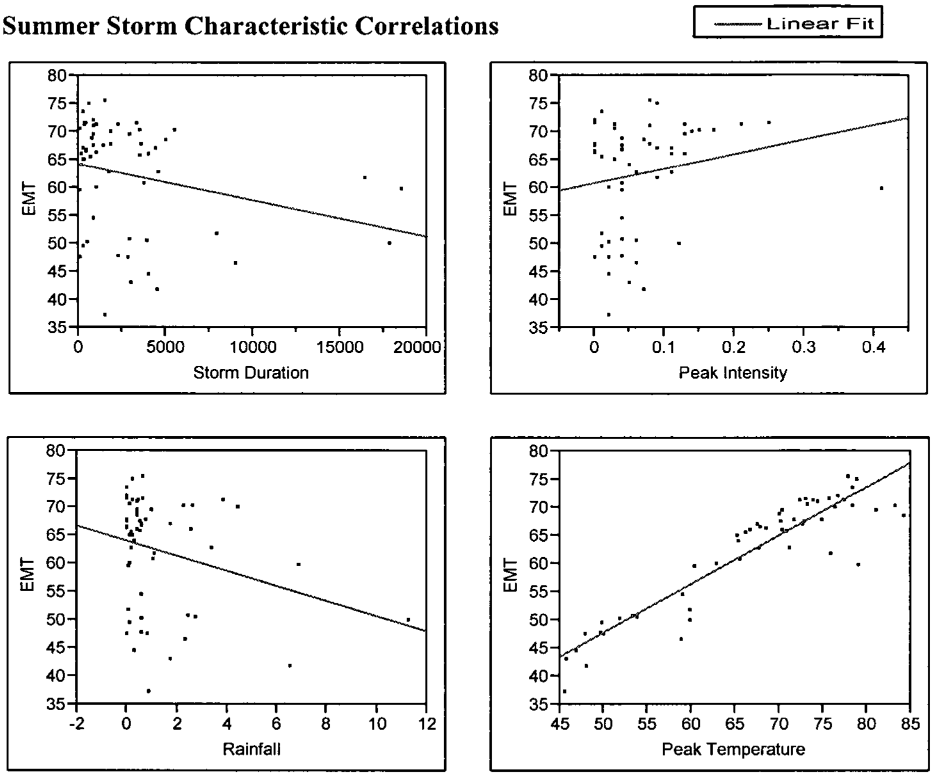


Table 5: Summer Storm Characteristic Correlations

Storm Duration

Parameter Estimates:		Y = 64.4 - 0.0007X		R^2 = 0.072
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	64.366951	1.534517	41.95	<.0001*
Slope	-0.00066	0.000316	-2.09	0.0410*

Peak Intensity

Parameter Estimates:		Y = 60.7 + 26.1X		R^2 = 0.037
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	60.741892	1.749546	34.72	<.0001*
Slope	26.114865	17.74189	1.47	0.1466

Rainfall Depth

Parameter Estimates:		Y = 64.1 - 1.3X		R^2 = 0.076
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	64.110373	1.455453	44.05	<.0001*
Slope	-1.340661	0.625787	-2.14	0.0365*

Peak Temperature

Parameter Estimates:		Y = 4.8 + 0.86X		R^2 = 0.838
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.807992	3.431693	1.40	0.1667
Slope	0.8613772	0.050633	17.01	<.0001*

Figure 5: Winter Storm Characteristic Correlations

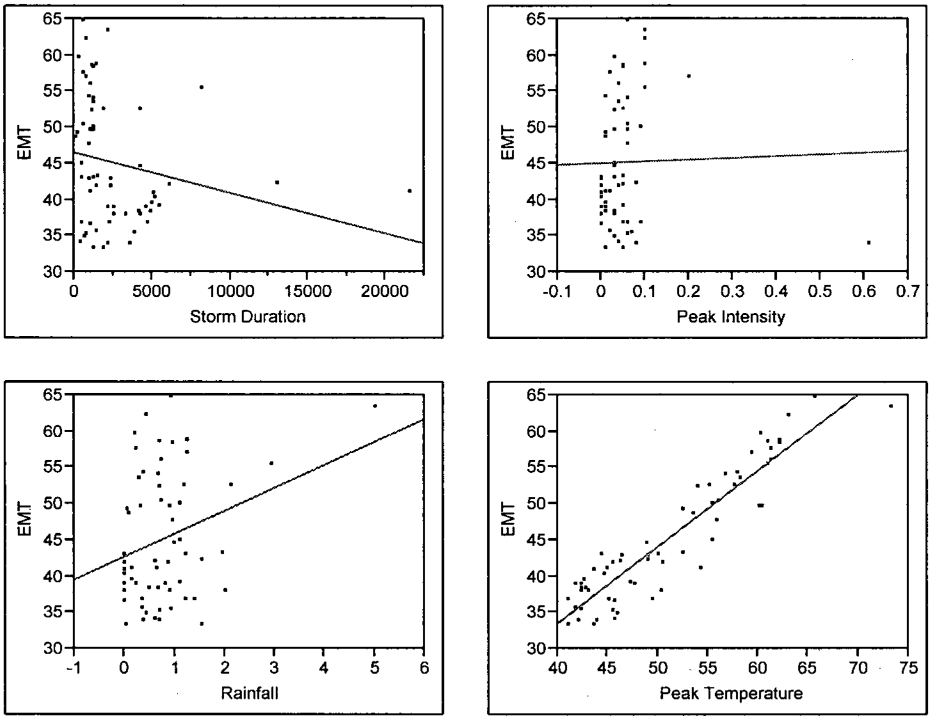


Table 6: Winter Storm Characteristic Correlations

Storm Duration

Parameter Estimates:		Y = 46.6 - 0.0006X		$R^2 = 0.045$
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	46.589619	1.411759	33.00	<.0001*
Slope	-0.00056	0.000334	-1.68	0.0990

Peak Intensity

Parameter Estimates:		Y = 45.0 + 2.5X		$R^2 = 0.0001$
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	44.979622	1.326939	33.90	<.0001*
Slope	2.5365977	14.07318	0.18	0.8576

Rainfall Depth

Parameter Estimates:		Y = 42.7 + 3.2X		$R^2 = 0.087$
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	42.656314	1.484241	28.74	<.0001*
Slope	3.1753451	1.326157	2.39	0.0198*

Peak Temperature

Parameter Estimates:		Y = -8.7 + 1.1X		$R^2 = 0.860$
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-8.72192	2.832738	-3.08	0.0031*
Slope	1.0541914	0.054862	19.22	<.0001*

5.1 - Annual Quartile Assessment

Examination of the EMTs by annual quartiles (Figure 9, Table 11) shows that the median runoff value of 52.4°F, (41.8°F_{q1}, 66.0°F_{q3})[4] is highly variable. The maximum and minimum values of 75.4°F and 33.3°F respectively, emphasize this point.

When comparing the values of the Detention Pond to the Runoff, it is evident that the medians are approximately the same, indicating a negligible change in EMTs. The annual median Detention Pond EMT is 52.8°F (35.8°F_{q1}, 67.6°F_{q3}) while the Retention Pond has an annual median EMT of 48.1°F (37.1°F_{q1}, 64.6°F_{q3}). The Retention Pond also has, both the lowest and highest measured EMT. From this data, the practice of maintaining a permanent pool of water to mitigate stormwater runoff effects has a counterproductive impact on the EMT of the stormwater in the basin. The Retention Pond, even with a lower median EMT, shows the highest EMT of all the systems. The EMTs of the Vegetated Swale followed fairly close to the hypothesis of the surface systems. The median Vegetated Swale EMT was 57.3°F (43.2°F_{q1}, 65.9°F_{q3}) While the maximum value does not reach quite as high as the values from the two ponds, the median value of the Vegetated Swale is the highest value calculated for any of the systems. This is most likely the result of the exposure of the stormwater to the variations in solar radiation and the location of the Vegetated Swale above ground, which does not allow for as much buffering of the temperatures, as a system with similar mass, located further underground.

The Gravel Wetland EMTs support the second hypothesis that the larger subsurface systems would have a greater thermal buffering. The median Gravel Wetland

[4] EMT values reported within parentheses are, q1 = the first quartile or the 25th percentile, q3 = the third quartile or the 75th percentile. This reporting style follows throughout the annual and seasonal quartile assessments.

EMT was 47.3°F (36.5°F_{q1}, 60.3°F_{q3}) which, is lower than either the Runoff or the Pond. The Gravel Wetland has a smaller spread of EMTs falling into the interquartile range than the Runoff, indicating the buffering of runoff temperatures. The Bioretention system also supports the second assumption of the hypothesis, with a median Bioretention EMT of 51.8°F (38.5°F_{q1}, 64.1°F_{q3}) shows less variability, and lower maximum EMTs than the Runoff.

The Hydrodynamic Separators (HDS) EMTs were similar to the Vegetated Swale and did not appear to provide much buffering of the stormwater runoff temperatures. With a median EMT of 56.6°F (39.3°F_{q1}, 66.8°F_{q3}), the HDS systems had higher EMTs and large variations similar to the Runoff. The two manufactured subsurface infiltration units, the ADS Infiltration System (ADS), and the StormTech Isolator Row (STIR), showed less variability than the Runoff EMTs, in similar fashion to the Gravel Wetland EMTs.

5.2 - Seasonal Quartile Assessment

The data was also analyzed as seasonal data sets to examine trends in summer and winter. The Runoff during the summer months (Figure 10, Table 12) shows a median EMT of 66.2°F (54.2°F_{q1}, 70.2°F_{q3}). During the winter months, (Figure 11, Table 13) the Runoff shows a median EMT of 42.5°F, (38.0°F_{q1}, 52.5°F_{q3}). Comparing these values to the annual values described earlier, it is apparent that the annual statistics do not have the ability to illustrate seasonal trends.

During the summer months, the Detention Pond has a smaller variation in EMT than the Retention Pond, which implies that the permanent pool of water in the Retention Pond is increasing temperatures of the stormwater while it passes through the system.

The thermal energy balance of a system (Figure 1) can explain this effect, where the variables that allow for heat transfer, surface exposure, the system mass, and the system depth are no longer adequate to mitigate the runoff temperatures. The Vegetated Swale, as stated previously, acts much like the Detention Pond, showing little to no buffering of the stormwater temperature from the Runoff.

The summer data for the Gravel Wetland has a median EMT of 60.9°F (48.8°F_{q1}, 66.0°F_{q3}). The lower first quartile implies that the Gravel Wetland is buffering the temperature from the Runoff during the summer months. The Bioretention system has a summer median EMT of 63.9°F (56.3°F_{q1}, 67.1°F_{q3}) and demonstrates a similar, but reduced buffering trend, visible when the Bioretention is compared to the Retention and Detention ponds.

The HDS systems follow a similar trend as the Runoff data, with the exception of the first quartile, which is higher than the Runoff and approaching the UOL for coldwater streams. Both subsurface infiltration systems show a strong ability to buffer and mitigate the thermal energy of the influent stormwater runoff before it discharges to the receiving waters. The STIR had a median summer EMT lower than either the Gravel Wetland or the ADS system; the STIR also has a slightly smaller interquartile range 53.7°F (46.7°F_{q1}, 59.4°F_{q3}). All of these EMTs fall within the optimal zone for coldwater streams.

The winter data for the Retention Pond has a median EMT of 39.0°F (33.9°F_{q1}, 47.2°F_{q3}), while the Detention Pond shows a median EMT of 38.7°F (33.3°F_{q1}, 50.4°F_{q3}). Contrasting the conclusions made from the summer data, the Detention Pond has a larger variation in stormwater temperatures than the Retention Pond, which implies that the permanent pool of water in the Retention Pond is cooler than the influent stormwater.

The data for the Gravel Wetland and the Bioretention show similar trends during the winter months, both systems having medians and first quartile values well below the lower optimum limit

The winter data for the ADS system has a median EMT of 42.5°F (47.2°F_{q1}, 53.9°F_{q3}) showing that the ADS system is better than the Gravel Wetland buffering and mitigating the colder influent stormwater runoff during the winter months. The STIR system has a median winter EMT lower than either the Gravel Wetland or the ADS system. At 40.4°F (38.5°F_{q1}, 48.7°F_{q3}) these cooler numbers appear similar to the HDS systems, and show that the STIR is doing less to buffer the temperature of the stormwater runoff during the winter months.

5.3 - Time Series Analysis

The data shown in the time series plots, (Figures 12, 13, and 14) show the yearly and seasonal trends in the EMTs for the Runoff data. The yearly trends appear to be consistent over the course of the four years of record. The EMTs never exceeding the 76°F mark, the threshold for the 'stress zone' of coldwater aquatic life. The data from the Retention Pond also shows the same trends, but in the summer months, EMTs exceed 80°F in at least one storm showing an additional increase in the temperature of the stormwater runoff while it is within the Retention Pond. During the summer months, April to September, the EMT of the Retention Pond is greater than that of the Runoff. This observation coincides with Galli (1990) who suggested that the runoff from urbanized areas during the summer months provided large temperature variations to ponds and subsequently to the receiving waters. The Detention Pond and the Vegetated Swale follow a similar pattern as the Runoff EMTs, with occasional differences, suggesting that these two systems neither buffer nor increase the temperatures of the stormwater. The Gravel Wetland data shows a smoother curve, indicating buffering of the temperature. While the Bioretention closely follows the pattern of the Gravel Wetland there are more spikes in the EMTs over the 4 years of record, indicating that the system is not buffering the temperature of the stormwater as efficiently as the Gravel Wetland. The HDS systems show the same pattern as the Runoff, with the large spikes in EMTs, and are warmer than the Runoff during most of the summer months. The HDS systems appear to be just as susceptible to air temperature variations as the Runoff or stormwater ponds. The two subsurface systems, the ADS, and the STIR, while generally cooler than the Runoff throughout the year, still show some substantial spikes in the EMTs during the summer months.

5.4 - Annual Cumulative Distribution Functions

Temperature indices, while may not in of themselves be the best way to measure the health of a coldwater stream ecosystem, but are helpful to determine if certain organisms are able to survive. Figures 15, 16, and 17 show the annual cumulative distribution functions (CDFs) for the EMTs of the Runoff and the eight systems. The exceedance values of the Upper Optimum Level (UOL) of 65°F for the annual assessment are shown in Table 14. The only system that exceeds the Lethal Limit of 80°F is the Retention Pond, ($p = 0.5\%$). The data from Figure 15 interestingly shows that the Retention Pond has a tendency towards lower EMT values than the Runoff until about 70°F. The Detention Pond shows a similar tendency until 65°F. The points where the ponds move away from the CDF of the Runoff, potentially indicates the limit of the ponds to buffer any additional increase in stormwater runoff temperatures. There is a greater input of thermal energy, than the ponds can handle via heat transfer to the air and ground, and the capacity of the mass of the system. Both the subsurface infiltration systems are cooler roughly 75% of the time. The subsurface infiltration systems are warmer than the Runoff, up until about 40°F, and then are cooler, implying that these systems mitigate both hot and cold runoff with a tendency towards the average annual groundwater temperature of 47°F (Heath 1983).

5.5 - Seasonal Cumulative Distributions Functions

The data is broken into the two six month seasons to examine the effects the systems have on the temperature of the stormwater during the warm and cold months of the year. Figures 18, 19, and 20 shows the summer CDFs for the EMTs, followed by Table 15 show the exceedance values of the systems for the UOL at 65°F for the summer months. The CDFs for the winter months below illustrate the probability of an EMT not to be exceeded, from which it is shown that during the winter months the EMTs of all the systems never exceed the UOL. Table 16 shows the maximum EMTs for each system during the winter months.

In the summer months of April to September, the Detention Pond appears warmer than the Runoff; the Vegetated Swale is for the majority of the storms, warmer than the Runoff, however, the Retention Pond remains cooler than the Runoff until it reaches the 70°F mark. The Detention Pond and the Vegetated Swale both reach the UOL at about the same exceedance of 65% and 63%; whereas the Retention Pond reaches the UOL at 44% exceedance showing the Retention Pond actually buffering the temperature of the stormwater runoff more than those two systems at temperatures below 70°F. However, the Retention Pond is the only system to get above the Lethal Limit (LL) of 80°F;

reinforcing the assumption that the larger surface systems will see greater variations in stormwater temperatures during the warmer summer months. The Gravel Wetland was always cooler, however, the Bioretention shows some buffering, but is limited to the higher temperatures, unlike the entire spectrum seen in the Gravel Wetland with 27% of the EMTs above the UOL. The HDS systems predictably, show either no buffering or an increase in the temperature of the stormwater runoff. The subsurface infiltration systems (ADS and STIR) both show a strong buffering of Runoff temperatures, with 9% and 4% of the EMTs above the UOL respectively.

During the winter months of October through March, both the Retention and Detention ponds were always cooler than the Runoff EMTs. The Gravel Wetland and the Bioretention systems are also both consistently cooler, showing little moderation of cold temperatures. During the winter months, the subsurface infiltration units have warmer EMTs towards the lower end of the spectrum, showing their ability to moderate the colder temperatures towards the average annual groundwater temperature.

5.6 - Frequency Distributions

In Figures 24, 25, and 26, the frequencies of the recorded real-time temperatures during the storm events are graphed to display the range of temperatures experienced by the systems over the monitoring period. These real-time temperatures are not flow-weighted and therefore have a wider range of values than the EMTs discussed earlier. The Runoff data shows a distribution with a majority of temperatures around 41°F and 42°F. The remainders of the temperatures appear uniformly distributed. The Retention and Detention ponds appear bimodal, with a peak at lower temperatures, which is attributed to the freezing temperature of water. The peaks of the systems occurring just slightly above 32°F, with that in mind the ponds show the great variability of temperatures assumed in the hypothesis. The Gravel Wetland has a distribution similar to that of the Runoff, but with a larger range of temperatures at the lower temperatures. The distribution of the Gravel Wetland illustrates a buffering of the higher temperatures from the Runoff. The Bioretention and Vegetated Swale have similar distributions, with a peak at the lower temperatures, followed by a second peak around the UOL. Neither system surpasses the LL of 80°F. The HDS systems appear to have roughly four peaks of temperatures showing how the systems experience a range of temperatures, a shorter range than the ponds, but at about the same frequencies as the temperatures in that range for the ponds. This illustrates the importance of the depth of the system in its ability to mitigate the runoff temperatures, rather than increase the runoff temperatures, as the ponds appear more likely to do. The ADS system has two large peaks. The first, the largest, around 42°F, is very near the annual average groundwater temperature of 47°F, showing the ability of the subsurface system to mitigate the runoff temperatures. The STIR, as expected, follows along the same lines as the ADS system. With peaks at roughly the same places, and explained through the same reasoning.

5.7 - Stormwater BMP Thermal Loading

The Event Mean Temperature (EMT) discussed in this paper, is analogous to an Event Mean Concentration (EMC) of other typical stormwater pollutants (i.e. TSS, Nitrogen, Phosphorous, etc.). EMCs measure and monitor the effectiveness of a stormwater system. Total Maximum Daily Loads (TMDLs) are based on an assimilative capacity of the receiving waters. A TMDL is the maximum amount of a pollutant that can be received by a body of water, while the body of water still meets the water quality criteria given to it. To create TMDLs, an analysis of the watershed of interest is performed to determine the loading of the waters' flushing time, and to determine how much of a pollutant a water body can accommodate. This loading of a pollutant is described in weight or volume per drainage area per time. An estimate of the loading can be calculated for the thermal energy associated with the stormwater runoff using an EMT. The estimate of the thermal energy is calculated as the thermal load per unit drainage area or the Thermal Load per Acre (TLA) for short. The area variable is generally not shown in loading values of TMDLs because it is associated with a particular watershed, with a given area. This research is intended for use in any watershed, and therefore has the area variable remaining in the thermal loading calculation

Equation 3: Event Thermal Loading Rate

$TLA = (EMT * Re * Cp)/A$

TLA = Thermal Load per Acre (BTU/(ac*sec))
EMT = Event Mean Temperature (°F)
R_e = Event Runoff (ft^3/sec)
C_p = Specific Heat of Water (J/(g*°K)), C_p = 4.18 J/(g*°K)
A = Drainage Area (acre)

Equation 4: Event Runoff

$R_e = I_e * P_j * R_v * A$

R_e = Event Runoff (ft^3/sec)
I_e = Average Event Intensity (ft/sec)
P_j = Precipitation Coefficient[5], P_j = 0.9
R_v = Runoff Coefficient[6], R_v = 0.92
A = Drainage area (ft^2)

Equation 5: Average Event Intensity

$I_e = P_T / T_d$

I_e = Average Event Intensity (ft/sec)
P_T = Total Precipitation (in)
T_d = Storm Duration (min)

Conversions: 1.0 Cubic Foot = 28.3 Grams (for water)
1.0 degrees Fahrenheit = 255.9 degrees Kelvin
1.0 British Thermal Unit = 1,055.1 Joules

[5] P_j = fraction of rainfall that produces runoff.
[6] R_v = function of impervious cover. $R_v = 0.05 + 0.9*$(Impervious Cover)

The steps taken to calculate a TLA for each event is show in the equations above. It is a concentration of pollutant (EMT) multiplied by the event volume per time (R_e), multiplied by the specific heat of water (C_p), divided by the drainage area (A). The event volume per time or the event runoff (R_e) is calculated using the Simple Method (Schueler, 1987) approach, slightly modified. Instead of an annual runoff, and an annual precipitation, these values are event specific. Each storm sampled, has a certain total precipitation, yielding a specific amount of runoff volume, calculated from the event specific rainfall hyetographs.

The event specific TLAs, described in Table 7, are summarized on an annual basis, and broken into two seasons, summer. Perhaps the most applicable number out of all of these is the mean summer TLA for each system. The summer months, being the warmest, test the limits of the system's ability to handle the thermal loading. For design considerations, this number would be most effective in sizing or choosing a stormwater treatment device. A more conservative design might use the maximum TLA during the summer, but for practical purposes, the mean summer TLA would appear to be sufficient for design.

The TLA could be used across any watershed, to allow the estimation of the thermal impact the drainage area will have on a receiving stream after the runoff is channeled through the particular stormwater treatment device. The TLAs reported here would need to be adjusted according to the size of the stormwater treatment device, the larger the system, the more mass it has, the greater its capability to exchange thermal energy. The mean summer TLA for a system can be multiplied by the drainage area, resulting in a value of BTU per second. This value could then compare to a regulatory standard of the area or receiving streams.

Table 7: TLA Summary

Units: BTU/acre/sec	Combined Annual TLA			Summer TLA			Winter TLA		
	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD
Runoff	189.3	262.1	260.7	227.2	306.2	297.7	169.0	221.3	216.0
Retention Pond	187.9	255.9	256.8	213.6	302.6	284.3	175.8	213.8	228.3
Detention Pond	177.4	249.0	255.1	219.7	303.7	303.9	144.7	208.4	207.9
Gravel Wetland	168.8	247.2	257.5	222.5	301.4	293.5	137.4	198.8	212.2
Bioretention	175.0	225.6	213.4	218.0	267.4	249.1	147.3	176.8	151.4
Vegetated Swale	219.3	299.3	299.4	225.6	364.2	360.4	186.7	254.2	243.9
HDS	188.7	269.7	274.4	238.2	325.8	313.5	134.3	207.0	210.2
ADS	164.0	274.1	330.0	190.0	316.4	366.5	101.4	231.8	299.1
STIR	173.2	234.4	207.4	165.0	242.2	201.6	195.8	225.1	218.3

The event specific TLAs in Table 7 do no follow the same pattern of effectiveness that was seen in the analysis of the EMTs. Since the TLAs are calculated on an event basis, it is a misrepresentation of the thermal loading from each system. This is because not all events are represented by every system, and therefore, it is difficult to compare the summarized event specific TLAs. The event specific TLAs are presented here to offer an estimation of the thermal loading from each system during an event.

To calculate a TLA for each system, that is representative of the analysis and results of the EMTs, the median EMT of each system was used, in conjunction with the total annual rainfall, and seasonal rainfall depths to get direct runoff values. Table 8 shows the average precipitation for New Hampshire, and the direct runoff, calculated by the Simple Method, from the drainage area for this study. The direct runoff numbers for each season would replace the event runoff (Re) in Equation 3 to calculate an annual, summer, and winter TLA (Table 9). These TLAs follow the results seen in the analysis of the EMTs. The STIR system has the lowest summer TLA, followed by the ADS and then the Gravel Wetland. These results show that these systems are discharging the lowest amount of thermal energy to the receiving streams during the summer months. These systems have the all the positive aspects of the variables associated with the thermal energy balance. They are subsurface systems, so they have the depth needed to transfer more heat to the ground surrounding them, they are the larger subsurface systems, so they have more mass to disperse the heat, and they limit the exposure of the stormwater to the variations in solar radiation.

Table 8: Seasonal Rainfall Depths

Season	Precipitation (in)	Direct Runoff (ft^3/season)
Annual	43.0	129,393
Summer	22.6	68,018
Winter	20.4	61,375

Table 9: Seasonal TLA

	Median EMT (°F)			**Thermal Loading Rates**		
				BTU/acre/year	BTU/acre/season	BTU/acre/season
	Annual	Summer	Winter	Annual	Summer	Winter
Runoff	52.4	66.2	42.5	195 E+6	129 E+6	75 E+6
Retention Pond	48.1	64.6	39.0	179 E+6	126 E+6	69 E+6
Detention Pond	52.8	68.6	38.7	196 E+6	134 E+6	68 E+6
Gravel Wetland	47.3	60.9	36.7	176 E+6	119 E+6	65 E+6
Bioretention	51.8	63.9	37.7	193 E+6	125 E+6	66 E+6
Vegetated Swale	57.3	68.6	44.7	213 E+6	134 E+6	79 E+6
HDS	56.6	66.3	38.4	210 E+6	130 E+6	68 E+6
ADS	49.2	60.3	42.5	183 E+6	118 E+6	75 E+6
STIR	47.6	53.7	40.4	177 E+6	105 E+6	71 E+6

CHAPTER 6

SUMMARY

6.1 – Stormwater BMP Event Mean Temperature

The results of this study demonstrate a range of thermal impacts from stormwater BMPs. The large surface systems were shown to have the largest thermal extremes, whereas the large subsurface systems were shown to have the greatest thermal buffering. The Gravel Wetland has a large surface area, but because of the filtration practices the system incorporates to treat the stormwater runoff, the Gravel Wetland has a "deeper" footprint than the large surface systems such as the ponds. The permanent pool of water in the Retention Pond acts as a heat sink during periods of extreme heat.

The Gravel Wetland, the ADS, and the STIR, have a strong capacity to act as thermal buffers. In addition, the data for these systems also suggest that these subsurface systems are, on average, reducing the summer temperatures and increasing the winter temperatures of the runoff to near the average groundwater temperature of 47°F. The annual comparison of the influent EMTs to the effluent EMTs of the ADS and STIR systems (Figure 29) show these systems pivoting about the average groundwater temperature. Calculating an intercept of the linear regression lines of the systems to the no treatment line reveals the intercept of the ADS to be at 47.3°F and the STIR intercepts at 47.5°F.

The summer EMTs of the two stormwater ponds, Bioretention, Vegetated Swale, and HDS systems, indicate that they provide little, to no effect on the runoff temperatures (see Appendix G). In contrast, the Gravel Wetland and STIR exhibit an ability to reduce runoff temperatures during the summer months. However, the Bioretention, and the HDS, as well as the Gravel Wetland, ADS, and STIR systems all have summer mean values that fall within the optimal zone for coldwater streams.

The Retention and Detention ponds appear to have some of the largest extremes in EMTs, again, indicating that these systems are producing large variations in the temperatures of the stormwater. Other systems showing variability, but not as pronounced as the two ponds, are the Vegetated Swale, and the HDS. The STIR also shows high values, but did not exceed the values of the runoff during the summer months.

The Retention Pond is the only system to exceed both the UOL and the Lethal Limit (LL) of 80°F, however the Detention Pond with a maximum EMT of 79.4°F comes very close. The HDS system has a 35.0% chance of exceeding the UOL, which is the highest exceedance value for any of the systems. This low non-exceedance value indicates that the HDS is not buffering the thermal energy as well as some of the other systems. The maximum HDS EMT (75.0°F) is still lower than that of the Runoff, Retention Pond, and Detention Pond. Therefore, unlike the ponds, the HDS systems do not appear to be increasing the temperature of the stormwater. The ADS and STIR systems have the lowest exceedance values of the UOL. At 5.0% for the ADS, and 1.5% for the STIR, these values presume to claim that these systems are very unlikely to discharge stormwater to a receiving stream above the upper optimum limit of 65°F for coldwater streams.

The natural thermal regime of a receiving stream is possibly the most important metric to compare with the EMTs of the stormwater BMPs. The best method would incorporate all of these metrics in determining the impact of the BMP on the receiving stream. The mean July temperatures of the systems are all within the stress zone for aquatic species, between 65°F and 80°F, with the exception of the two subsurface infiltration systems, which fall within the optimum zone of 45°F to 65°F for coldwater aquatic species. The mean July temperature of the Gravel Wetland is just above the UOL at 66°F, illustrating that the deeper systems of the ADS and STIR systems are able to buffer the runoff temperatures more effectively.

6.2 - Natural Streams and Mixing

The natural thermal regime of a stream describes the frequency of the seasonal highs and lows of the temperatures found within that stream. This concept is important to consider when describing the health of a stream. These ranges of temperatures play a vital role in the life cycles of the species living within this stream ecosystem; affecting such life processes as reproducing, eating, and other basic survival needs.

Stormwater BMPs, after holding, and treating the runoff, often discharge to a nearby water of body, the receiving waters. While mean July temperatures are helpful to determine the health of the stream at the extremes, the thermal regime of a stream is crucial to the ecosystem health throughout the year. To reduce the impact that runoff has on a stream, it may be necessary to design the treatment of the runoff to discharge the increased temperature of the runoff to match, as closely as one can, to the natural thermal regime of the receiving waters. Mixing of the effluent of the stormwater BMPs and the passing flow of the stream is also an important point. For simplicity, this paper presumes a one hundred percent mixing of the effluent and stream flow.

Three streams are considered in this paper, College Brook, Wednesday Hill Brook, and Oyster River. These three streams have been monitored for various water quality concerns, including temperature. College Brook is separated into two segments, an upstream section, and a downstream section. These streams are presented here to illustrate what a natural thermal regime of a cold or cool water stream might look like. College Brook is located on the University of New Hampshire (UNH) campus, and Wednesday Hill Brook is located a few miles west of the UNH campus, near James Farm. The Oyster River is the upper reach of the river, located in southern New Hampshire, where it is still a first order stream.

College Brook upstream has temperatures above 65°F 11% of the time, Wednesday Hill Brook exceeds 65°F 3% of the time and Oyster River falls very close to College Brook with an exceedance of 14% (Figure 6). As an example, looking at the Gravel Wetland, the EMTs exceed the upper optimum limit (UOL) of 65°F 13% of the time. Therefore, it could be hypothesized that the Gravel Wetland would be a good fit for perhaps College Brook upstream or Oyster River. Finding a system for Wednesday Hill Brook, the StormTech Isolator Row, has an exceedance value at 65°F of 1.5%. Slightly higher than that of the natural stream, which may have a negative impact, depending on the reaction of the aquatic species living within the stream being subjected to cooler water, more often.

Now looking at the other end of the spectrum, the lower optimum limit (LOL) of the streams, College Brook upstream and Oyster River both do not exceed 45°F 45% of the time, and Wednesday Hill Brook reaches that same limit at 50%. This LOL is more important during the cold winter months, and needs a stormwater BMP that can create those same temperatures as often as is seen naturally. Of the systems tested the Gravel Wetland and the subsurface infiltration unit, STIR, yielded similar non-exceedance values of the LOL. These results indicate that the use of infiltration practices for stormwater treatment will be able to create similar thermal regimes as the natural systems.

The monitoring station in the downstream section of College Brook is a first order stream, with a drainage area about 740 acres. Impervious cover that accounts for 23% of the drainage area, as well as nine upstream road crossings affects the stream. Contrasting the impacted College Brook, is Wednesday Hill Brook, which is also a first order stream. Wednesday Hill Brook has a drainage area of about 250 acres, of which, only 14% is impervious, and has no upstream road crossings. Using these two streams as a lower limit, Wednesday Hill Brook, and upper limit, College Brook downstream, applying the cumulative distributions of the stormwater BMPs illustrates which systems best fit the natural thermal regime of streams falling within this range. In Figure 7, the Gravel Wetland, STIR, Detention Pond, and Vegetated Swale are compared to these upper and lower limits. Both of the stormwater systems with infiltration fall within the range of the two streams while also in the optimum zone for aquatic species. The other two systems show trends towards warmer temperatures, beyond the upper limit set by the impacted stream.

The mean July temperature of College Brook was 66.3°F, statistically different from that of Wednesday Hill Brook, with a mean July temperature of 61.2°F (see Appendix E). All of the systems have mean July temperatures statistically different from both streams. Both the Gravel Wetland and the STIR appear to split the difference between the natural thermal regimes of the streams between the LOL and UOL. All of the systems have thermal regimes statistically different from Wednesday Hill Brook, with only the Detention Pond differing from College Brook. The Vegetated Swale however, is, the closest of the remaining three systems to being statistically different from College Brook also (see Appendix G).

To understand how these EMT from the stormwater BMPs effect the temperature of the receiving stream, an example of a mixing curve was created (Figure 8). This figure assumes that all of the effluent stormwater flow and thermal energy is mixed with the stream flow. The different lines represent the amount of effluent flow divided by the total resulting flow. For example, if the stormwater BMP was discharging 0.5cfs and the stream was discharging 0.5cfs, than the 50% line would be considered. Therefore, if a bioretention was discharging 0.5cfs into a stream flowing at 0.5cfs, and the EMT was 20°F warmer than the dry flow of the channel, then the channel would in essence, increase its temperature by 10°F.

This is a hypothetical exercise, and provides a first order assessment of the impact of a stormwater BMP on a natural stream. A more detailed analysis would require additional information. Proper monitoring of the point of mixing is required, and then development of a model to predict the outcome of the mixing of the thermal loads of the effluent discharge and the stream discharge. Detailed modeling is beyond the scope of this report, but is important in understanding how these thermal loads will affect the natural thermal regimes of the receiving streams. The assumption of 100% mixing is most likely not the case. The mixing of the thermal energy is probably very similar to that of other water quality constituent, and is effected by the same variables. Mixing could be effected by effluent location, more complete mixing might occur in the riffled sections of streams.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 - Conclusions

The temperature of runoff is affected within the systems by its exposure to the air, the depth of the system, and the mass, or size of the system. Exposure of the systems to the air, affect the temperature of the stormwater by the variations in solar radiation. During the summer months, it is expected to see an increase in stormwater temperatures within the systems that have a large surface area. That system also affects the temperature by the physical dimensions of its treatment cells. The larger the system is, the greater the capability it has to mitigate the temperatures. Additionally, that same system, with a large surface area, and a large mass, can further mitigate the runoff temperatures the deeper it is. The deeper the system is within the ground, the more cool earth the stormwater encounters to mitigate the temperature of the stormwater. Therefore, systems, with a small surface footprint, but a large subsurface footprint, will be the best systems to mitigate the stormwater temperatures. These systems will be able to buffer the warm summer runoff, as well as the cool winter runoff, yielding effluent temperatures near the average groundwater temperature.

A key treatment mechanism of a stormwater BMP is filtration. This mechanism allows the runoff to enter the subsurface material where it decreases the warmer temperatures, and possibly increases the colder temperatures. Filtration is found in the subsurface systems, listed from least effective to most effective at mitigating runoff temperatures; Bioretention, Gravel Wetland, ADS Infiltration System and StormTech Isolator Row. The ADS system is the larger, and deeper of the two subsurface infiltration systems, but the STIR bypasses the larger flows, and therefore only treats the cooler beginning and end of the summer storms.

Conventional stormwater BMPs that include detaining the stormwater in a pool as part of the treatment design are less effective at mitigating the temperature of the runoff than the systems that incorporate filtration. These pools of water act as heat sinks during the summer months, and mix with the effluent of the conventional systems, increasing the runoff temperatures further. Conventional systems are generally not deep systems, as they use sedimentation as the primary water treatment mechanism. Stormwater ponds, which tend to be large structures, with large surface areas, and treatment volumes above ground, are not as capable as the subsurface systems in mitigating the temperature of the stormwater runoff.

7.2 – Future Research

This data set could be expanded to include all systems monitored at the UNHSC site over their respected life spans. Future research and data analysis could further explore the connection between BMP correlation of runoff temperatures and changes to and mitigation of receiving stream thermal regimes. The information could supplement the UNHSC data with data collected for various stream types. This data will be used to examine thermal regimes for the various stream types with respect to thermal performance characteristics. Such comparisons could include BMP specific temperature related thermal impact curves (BTU/Acre/Second) for various stream types. The correlation would be normalized to a specific discharge of a receiving stream such that impacts could be scaled for varying stream sizes.

Figure 6: Cumulative Distribution of Natural Streams

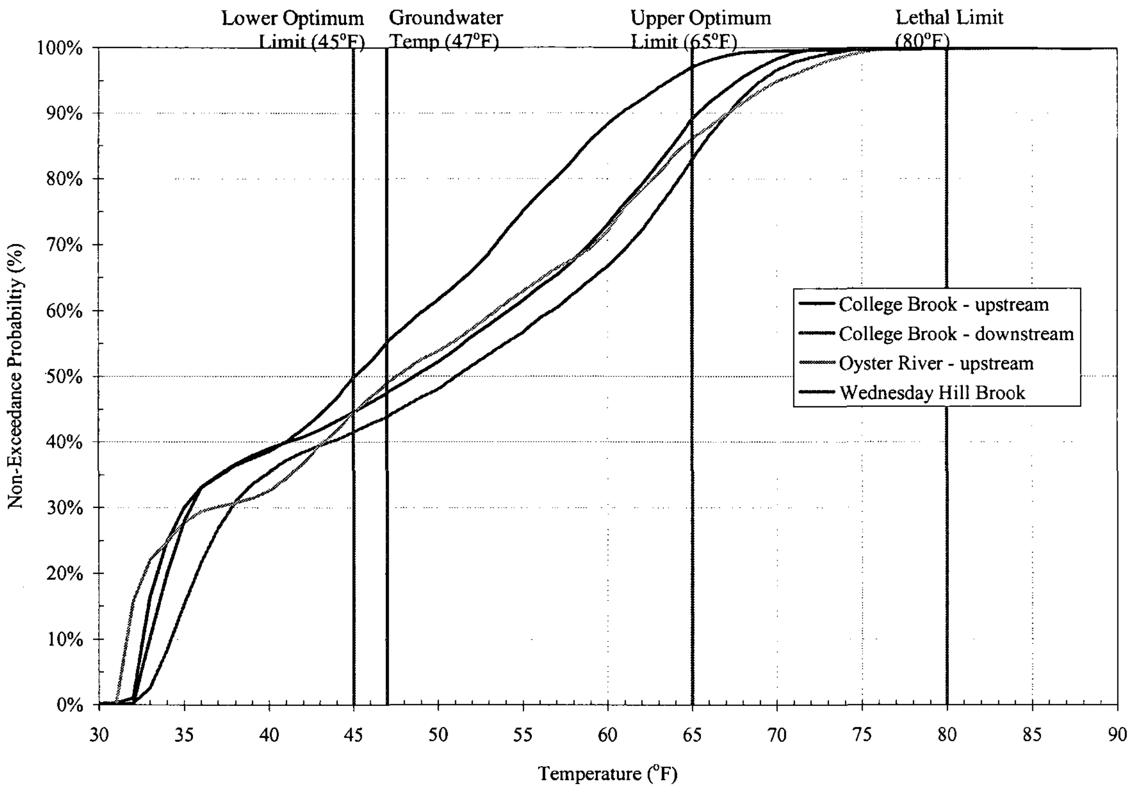


Figure 7: Cumulative Distribution of Natural Streams vs. Stormwater BMPs

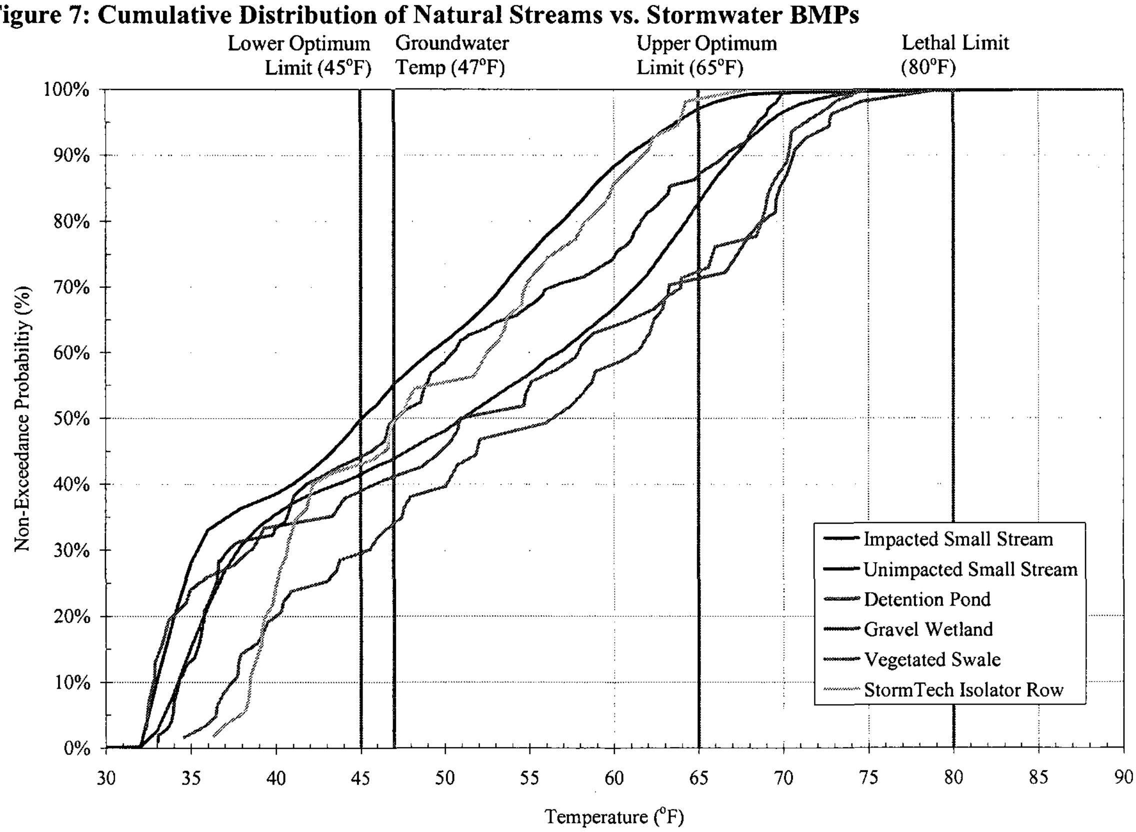


Table 10: CDF Summary of Natural Stream vs BMP

Stream or System	% Exceedance		Maximum Value†	Mean July Temperature
	LOL* (45°F)	UOL** (65°F)	(°F)	(°F)
College Brook - u/s	55%	11%	80	66.3
College Brook - d/s	58%	17%	80	67.3
Wednesday Hill Brook	50%	3%	90	61.2
Oyster River	55%	14%	79	66.5
Detention Pond	61%	28%	79	72.2
Gravel Wetland	56%	13%	70	66.0
Vegetated Swale	70%	27%	75	70.3
StormTech Isolator Row	56%	1%	68	58.5

*LOL – Lower Optimum Limit

**UOL – Upper Optimum Limit

† Values listed for streams are direct temperature measurements, while values for the stormwater BMPs are EMTs.

Figure 8: 100% Mixing of EMT and Stream

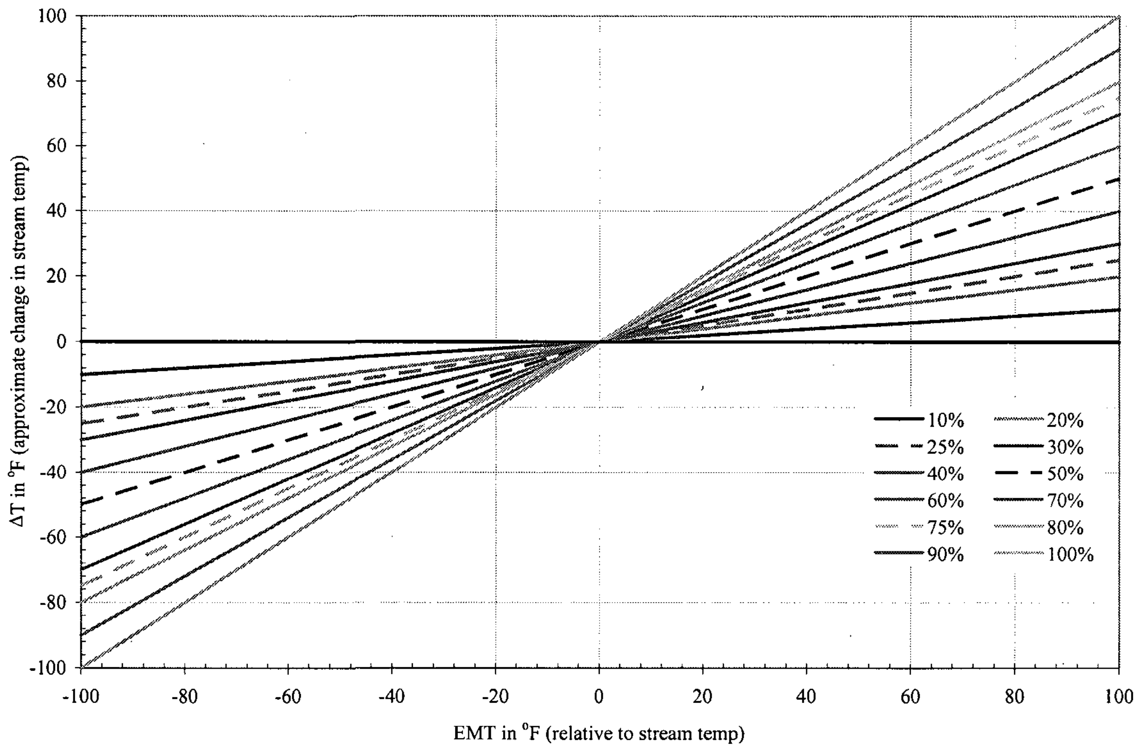


Figure 9: Annual Quartile Distributions for Event Mean Temperatures[7]

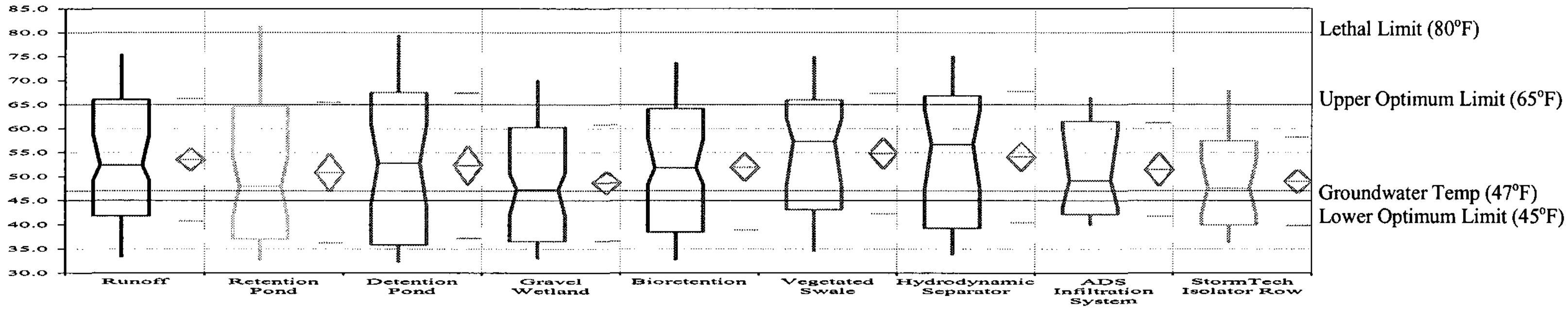


Figure 10: Summer Quartile Distributions for Event Mean Temperatures[7]

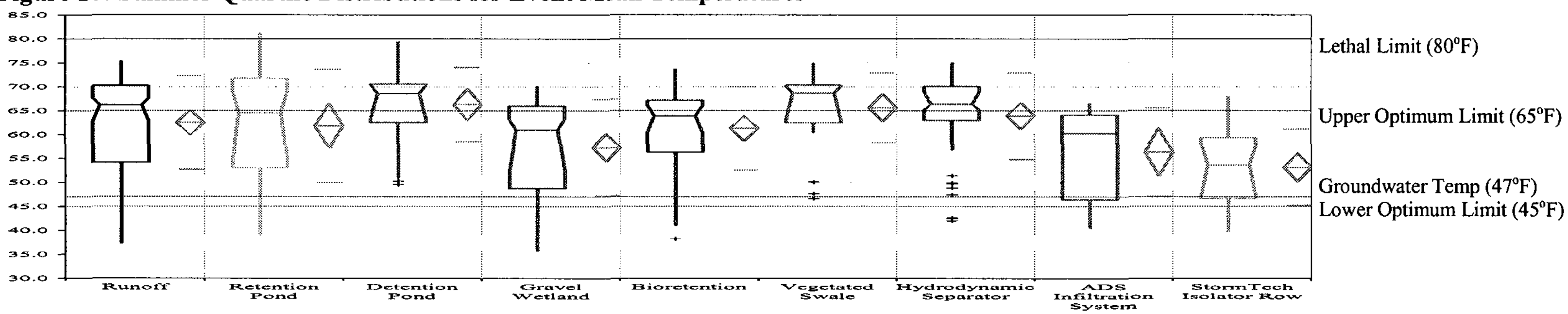
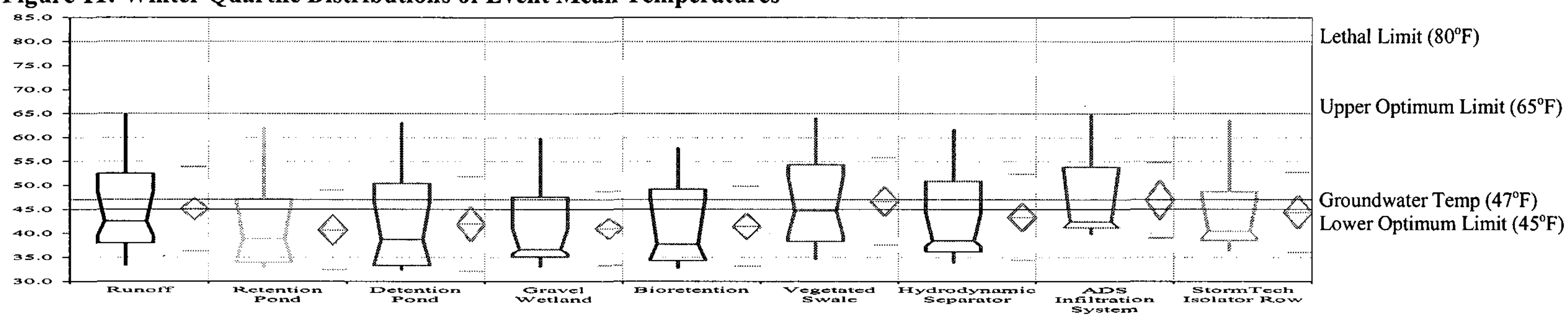


Figure 11: Winter Quartile Distributions of Event Mean Temperatures[7]



[7] The y-axis shows Event Mean Temperatures (°F). Interpretation of Figures 9, 10, and 11 is the same as described earlier for Figure 2.

Table 11: Annual Quartile Assessment Summary

FULL DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	120	56	54	102	83	63	82	33	55
	Minimum	33.3	32.7	32.3	33.0	32.7	34.6	33.8	39.9	36.3
	25th Percentile	41.8	37.1	35.8	36.5	38.5	43.2	39.3	42.2	40.0
	Median	52.4	48.1	52.8	47.3	51.8	57.3	56.6	49.2	47.6
	75th Percentile	66.0	64.6	67.6	60.3	64.1	65.9	66.8	61.5	57.5
	Maximum	75.4	81.3	79.4	70.0	73.7	75.0	75.0	66.4	67.8
	Standard Deviation	12.7	14.6	15.1	12.0	13.1	12.6	13.6	9.7	9.2
	Mean	53.5	50.9	52.3	48.7	51.9	54.8	54.1	51.5	49.0

Table 12: Summer Quartile Assessment Summary

SUMMER DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	58	27	23	48	44	27	43	16	29
	Minimum	37.3	32.7	32.3	33.0	32.7	34.6	42.0	40.5	39.8
	25th Percentile	54.2	52.9	62.5	48.8	56.3	62.4	63.0	46.4	46.7
	Median	66.2	64.6	68.6	60.9	63.9	68.6	66.3	60.3	53.7
	75th Percentile	70.2	71.7	70.6	66.0	67.1	70.3	70.0	64.1	59.4
	Maximum	75.4	81.3	79.4	70.0	73.7	75.0	75.0	66.4	67.8
	Standard Deviation	9.8	11.8	7.8	10.1	8.7	7.3	9.1	9.3	7.9
	Mean	62.5	61.8	66.3	57.3	61.2	65.6	63.8	56.3	53.2
Mean July Temperatures (°F)		67.1	77.9	72.2	66.0	67.7	70.3	69.8	63.4	58.5

Table 13: Winter Quartile Assessment Summary

WINTER DATA SET		Runoff	Retention Pond	Detention Pond	Gravel Wetland	Bioretention	Vegetated Swale	Hydrodynamic Separator	ADS Infiltration System	StormTech Isolator Row
EMT (°F)	Sample Size	62	29	31	54	39	36	39	17	26
	Minimum	33.3	32.7	32.3	33.0	32.7	34.6	33.8	39.9	36.3
	25th Percentile	38.0	33.9	33.3	35.1	34.3	38.3	36.2	41.2	38.5
	Median	42.5	39.0	38.7	36.7	37.7	44.7	38.4	42.5	40.4
	75th Percentile	52.5	47.2	50.4	47.6	49.2	54.3	50.9	53.9	48.7
	Maximum	64.8	62.0	63.1	59.8	57.8	64.0	61.6	64.7	63.7
	Standard Deviation	8.8	8.3	9.9	7.7	8.4	9.1	9.0	7.9	8.4
	Mean	45.1	40.7	41.9	41.0	41.5	46.7	43.4	46.9	44.4

Figure 12: Time Series of Event Mean Temperatures

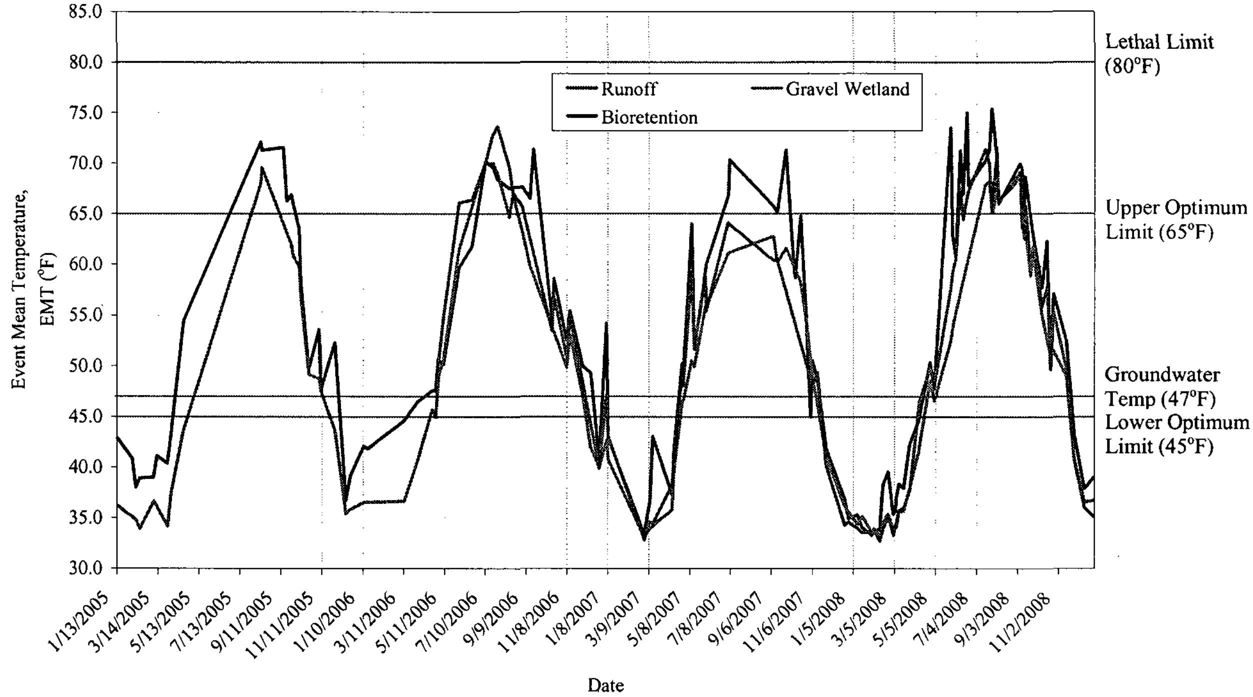


Figure 13: Time Series of Event Mean Temperatures

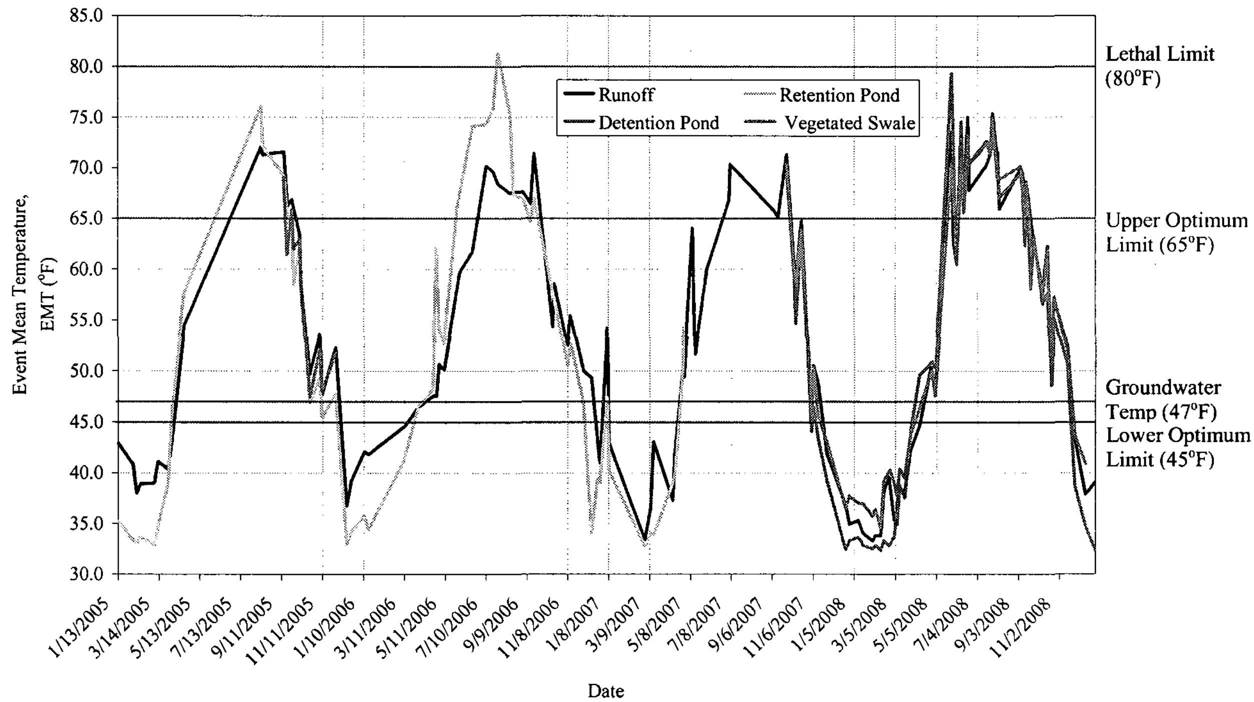


Figure 14: Time Series of Event Mean Temperatures

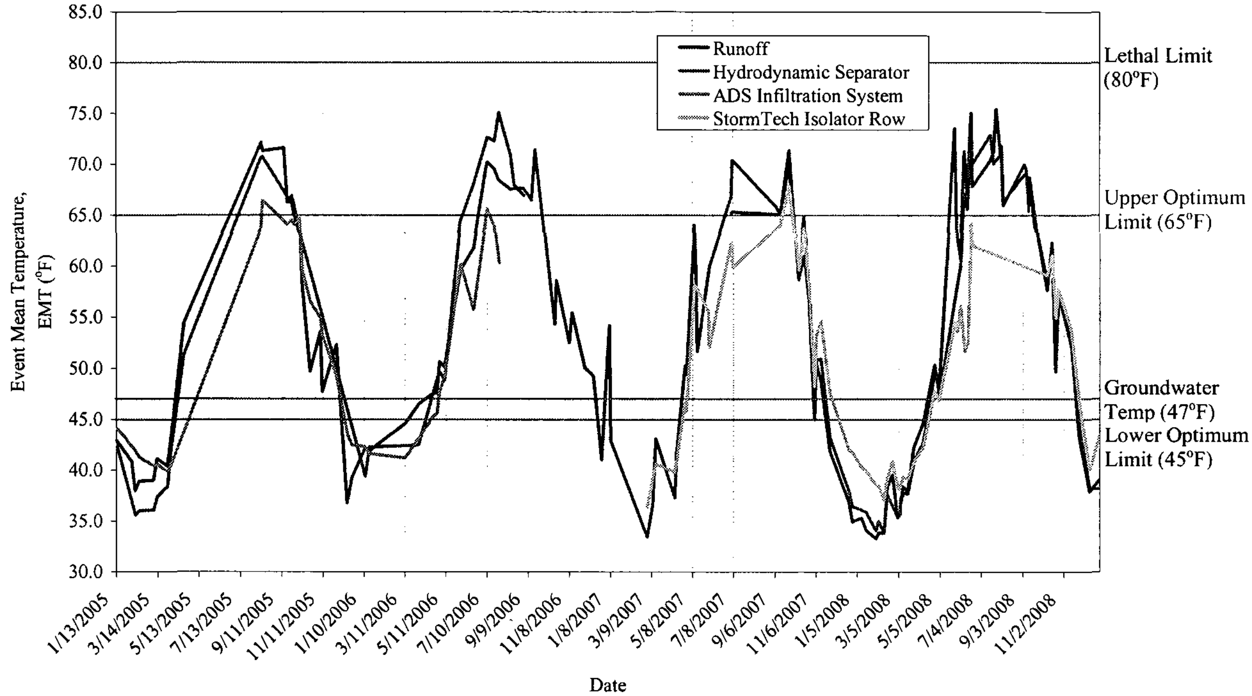


Figure 15: Cumulative Distribution Function for Event Mean Temperatures

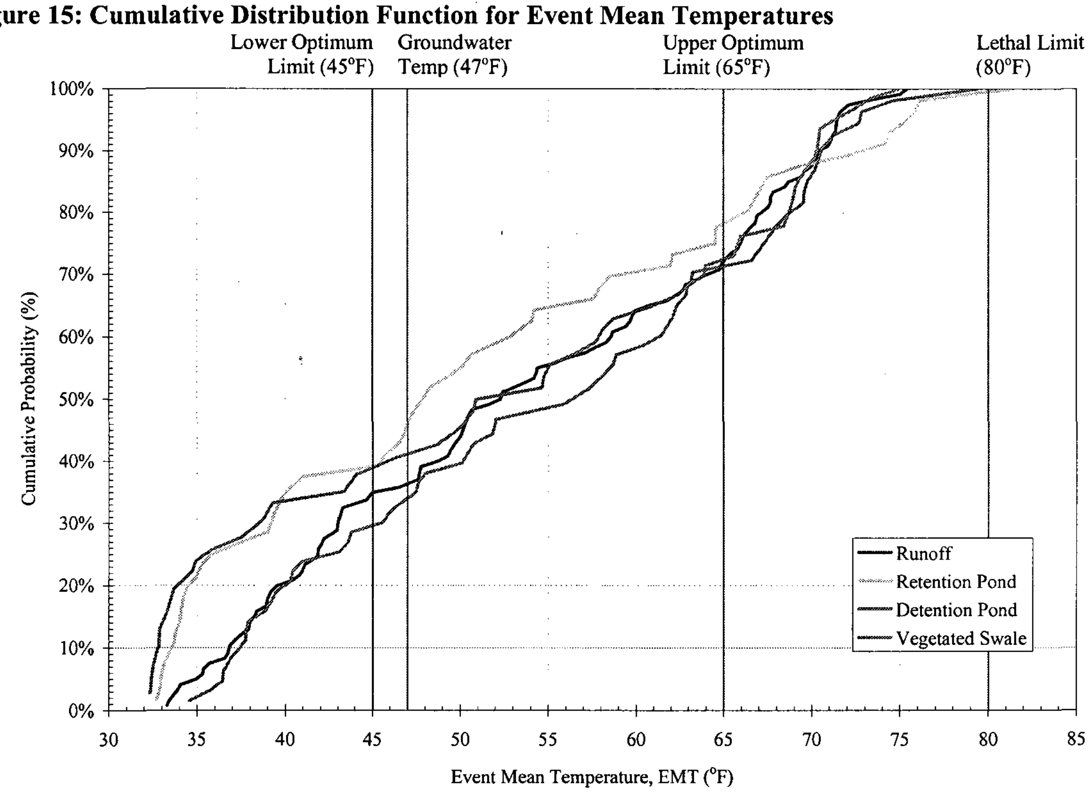


Figure 16: Cumulative Distribution Function for Event Mean Temperatures

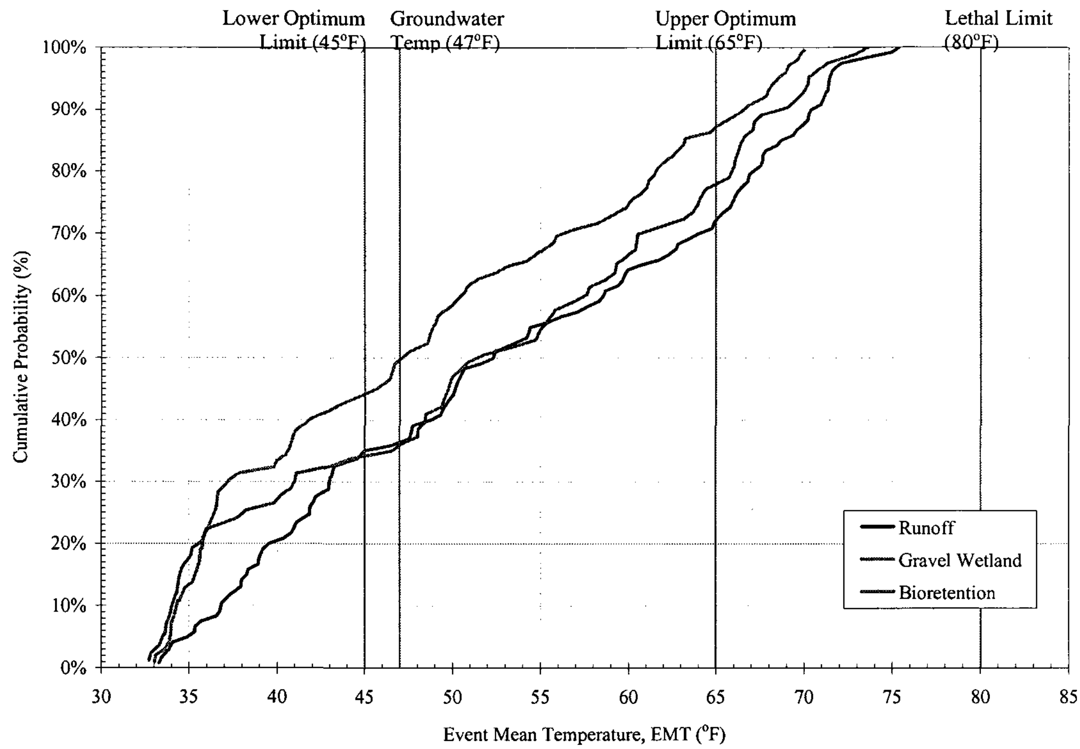


Figure 17: Cumulative Distribution Function for Event Mean Temperatures

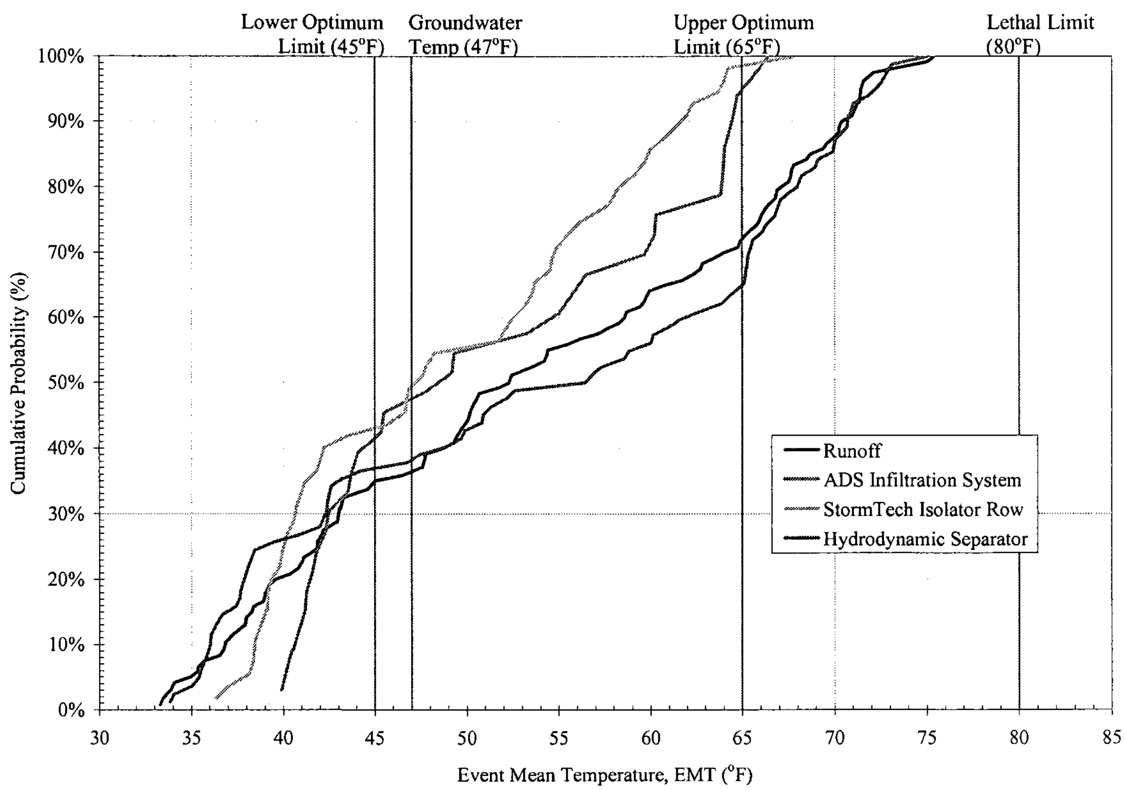


Table 14: Summary Table for Cumulative Distribution Function

FULL DATA SET	% Exceedance		Maximum EMT	Mean July Temperature
System	Upper Optimum Limit (65°F)	Lethality Limit (80°F)		
Runoff	27.5%		75.4°F	67.1°F
Retention Pond	21.0%	0.5%	81.3°F	77.9°F
Detention Pond	28.5%		79.4°F	72.2°F
Gravel Wetland	13.0%		70.0°F	66.0°F
Bioretention	22.0%		73.7°F	67.7°F
Vegetated Swale	27.5%		75.0°F	70.3°F
Hydrodynamic Separator	35.0%		75.0°F	69.0°F
ADS Infiltration System	5.0%		66.4 F	63.4°F
StormTech Isolator Row	1.5%		67.8 F	58.5°F

Figure 18: Summer Cumulative Distribution Function for Event Mean Temperatures

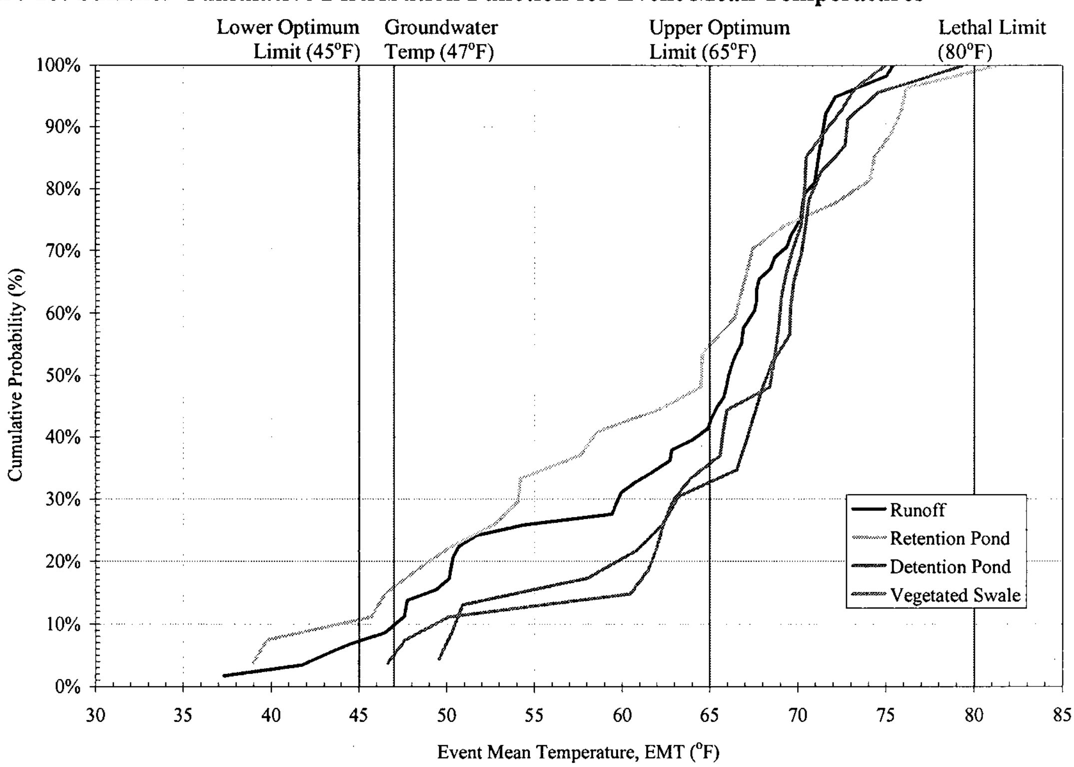


Figure 19: Summer Cumulative Distribution Function for Event Mean Temperatures

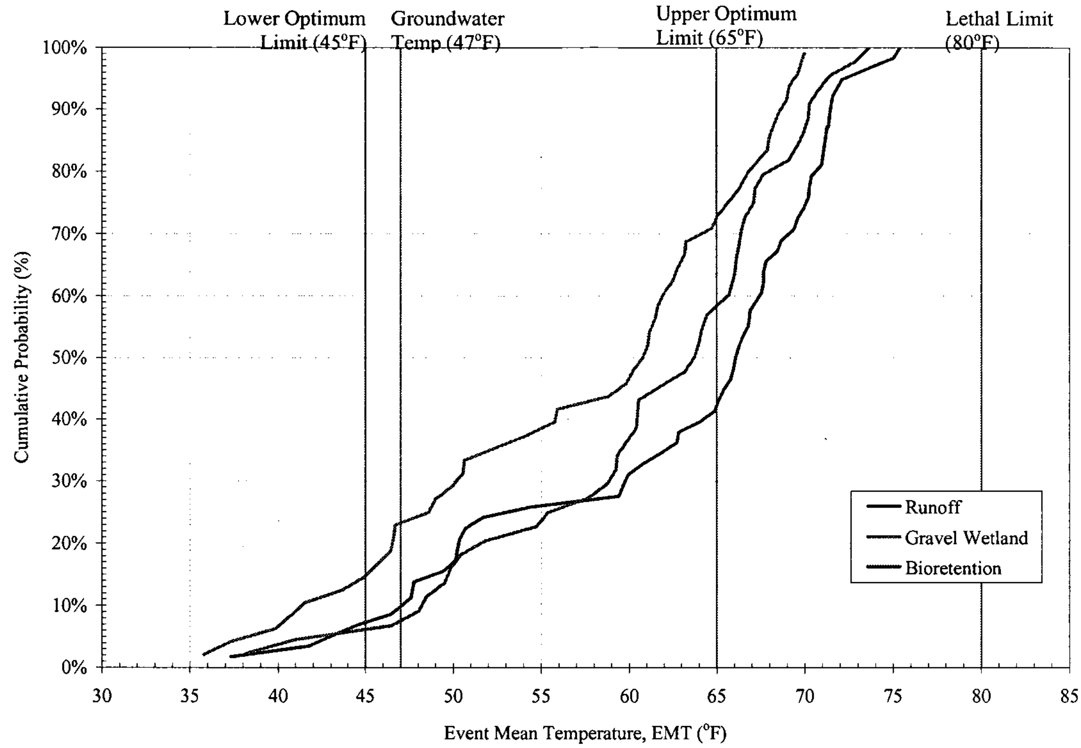


Figure 20: Summer Cumulative Distribution Function for Event Mean Temperatures

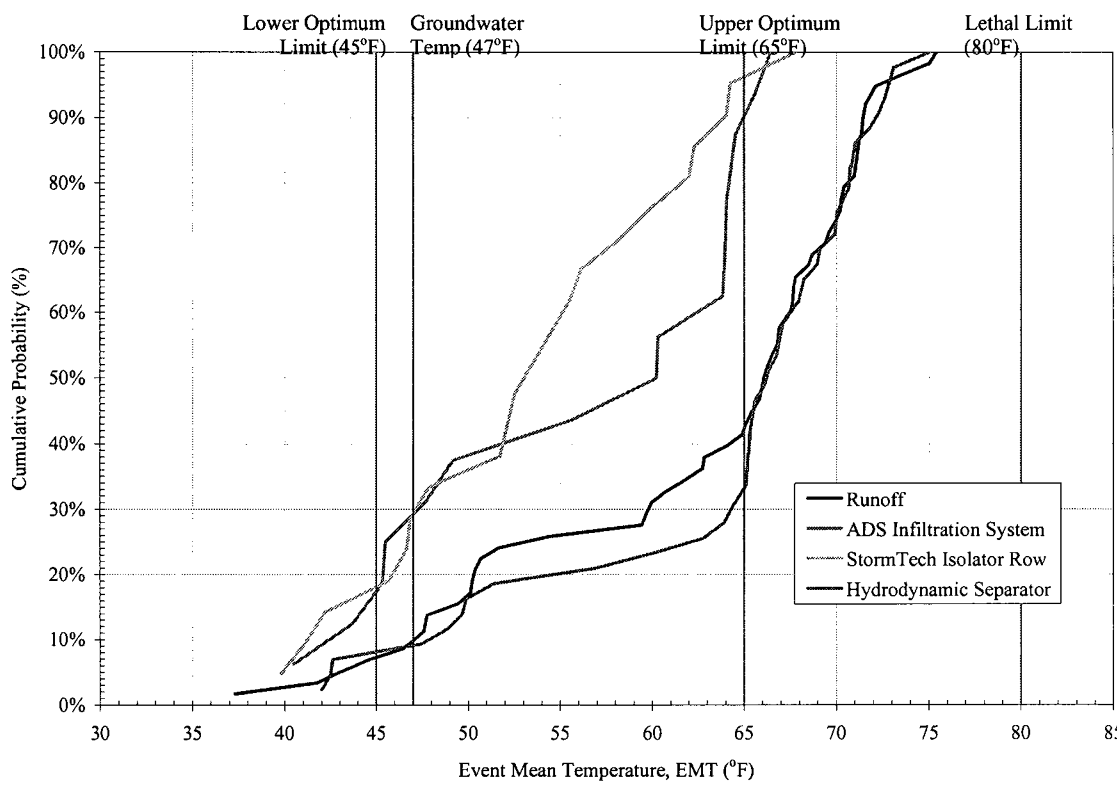


Table 15: Summer Summary Table for Cumulative Distribution Function

SUMMER DATA SET	% Exceedance		Maximum Summer EMT	Mean July Temperature
System	Upper Optimum Limit (65°F)	Lethality Limit (80°F)		
Runoff	58.0%		75.4°F	67.1°F
Retention Pond	44.0%	1.0%	81.3 F	77.9°F
Detention Pond	63.0%		79.4°F	72.2°F
Gravel Wetland	27.0%		70.0°F	66.0°F
Bioretention	41.5%		73.7°F	67.7°F
Vegetated Swale	65.0%		75.0°F	70.3°F
Hydrodynamic Separator	66.0%		75.0°F	69.0°F
ADS Infiltration System	9.0%		66.4°F	63.4°F
StormTech Isolator Row	4.0%		67.8°F	58.5°F

Figure 21: Winter Cumulative Distribution Function for Event Mean Temperatures

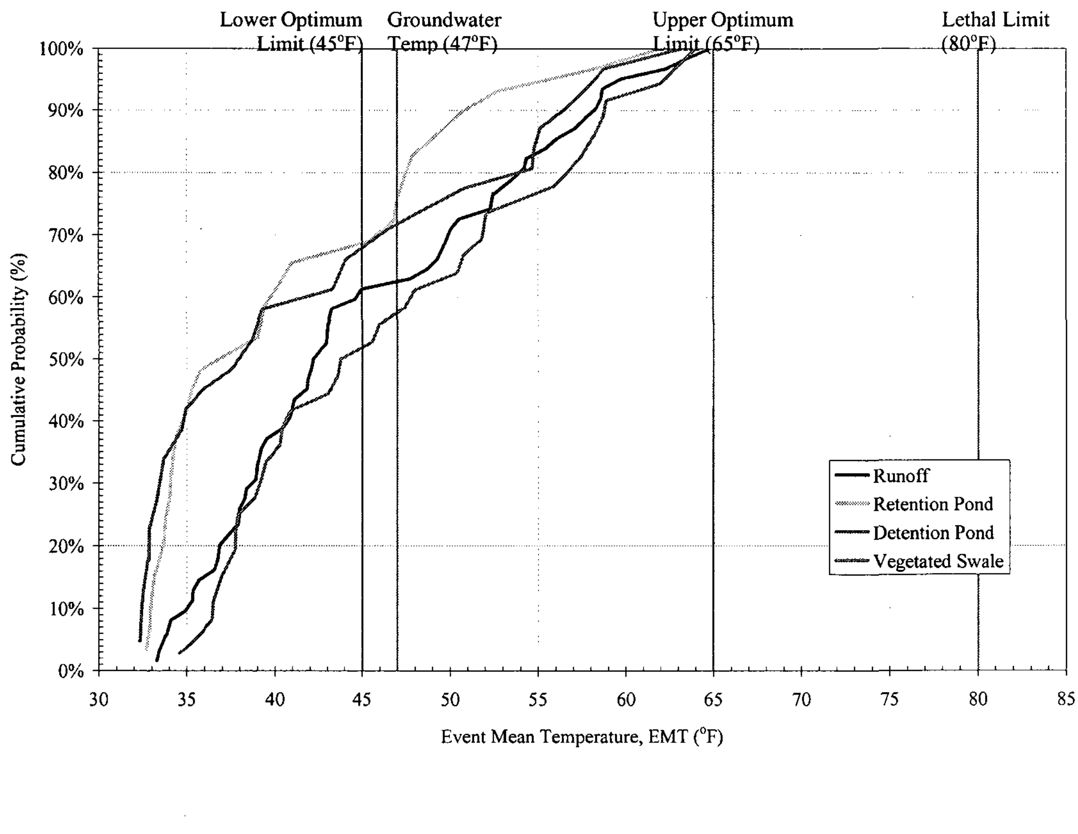


Figure 22: Winter Cumulative Distribution Function for Event Mean Temperatures

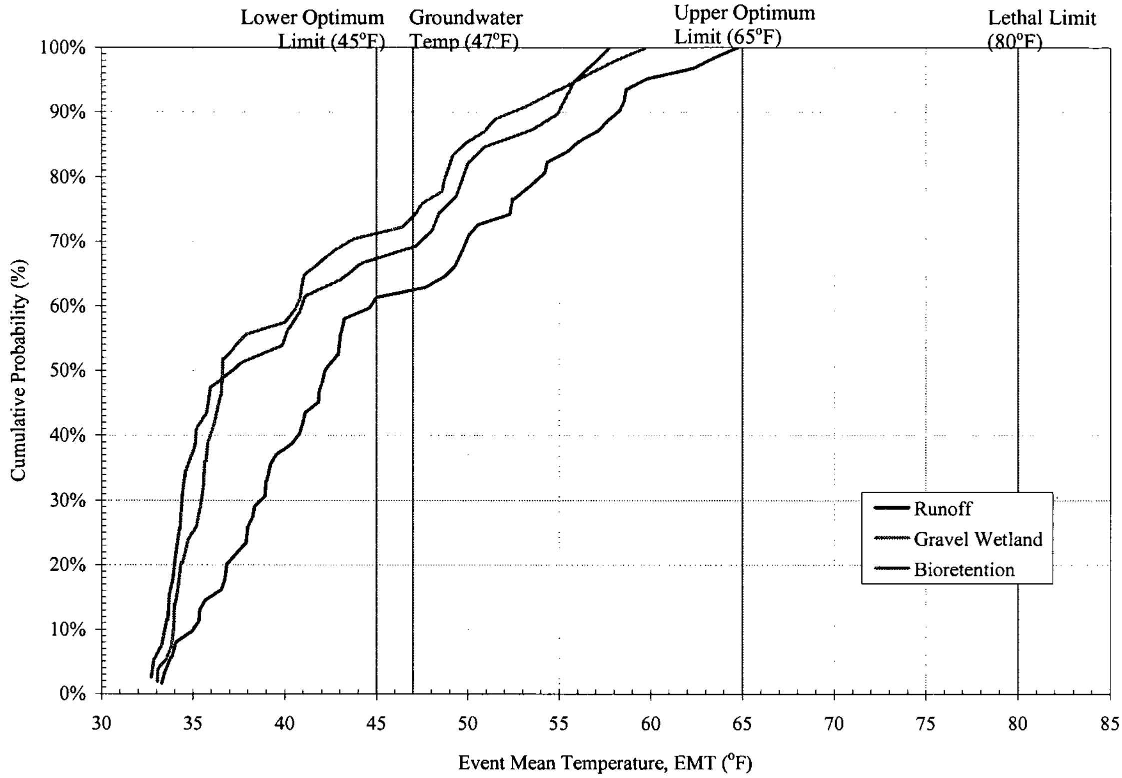


Figure 23: Winter Cumulative Distribution Function for Event Mean Temperatures

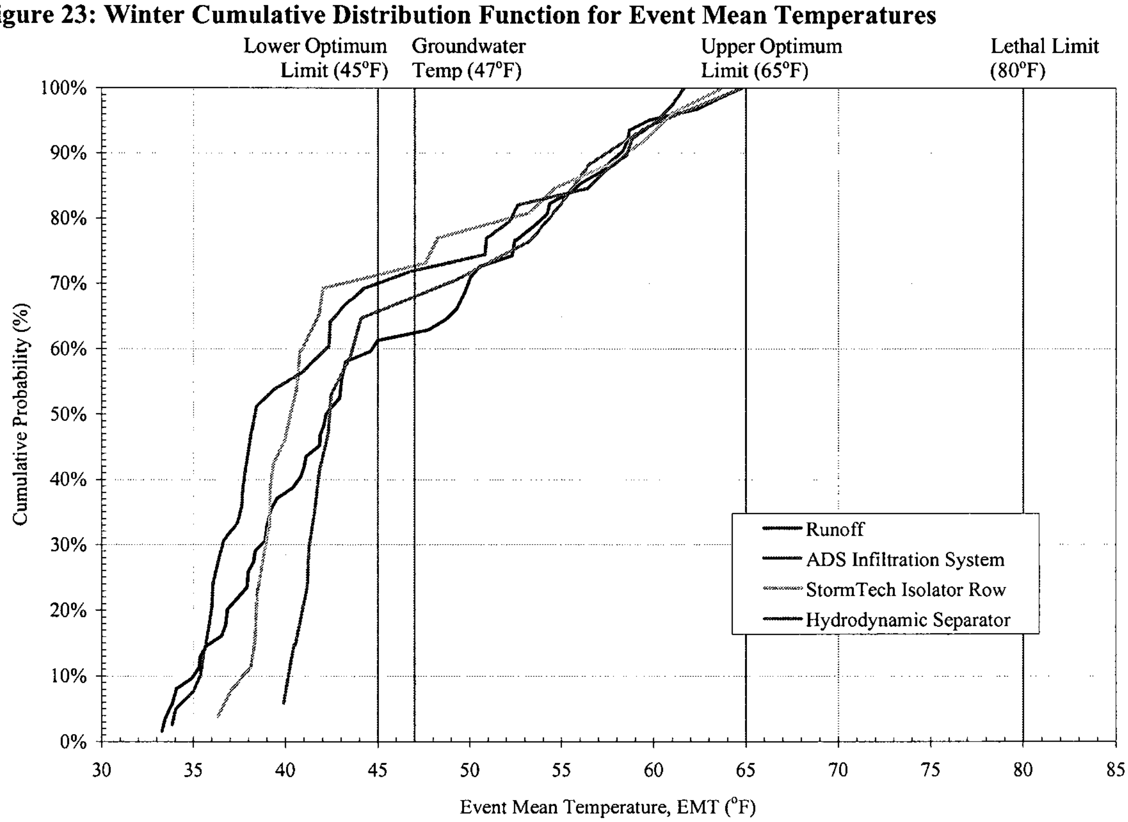


Table 16: Winter Summary Table for Cumulative Distribution Function

WINTER DATA SET System	Maximum Winter EMT
Runoff	64.8°F
Retention Pond	62.0°F
Detention Pond	63.1°F
Gravel Wetland	59.8°F
Bioretention	57.8°F
Vegetated Swale	64.0°F
Hydrodynamic Separator	61.6°F
ADS Infiltration System	64.7°F
StormTech Isolator Row	63.7°F

Figure 24: Frequency Distribution for Real-Time Temperatures

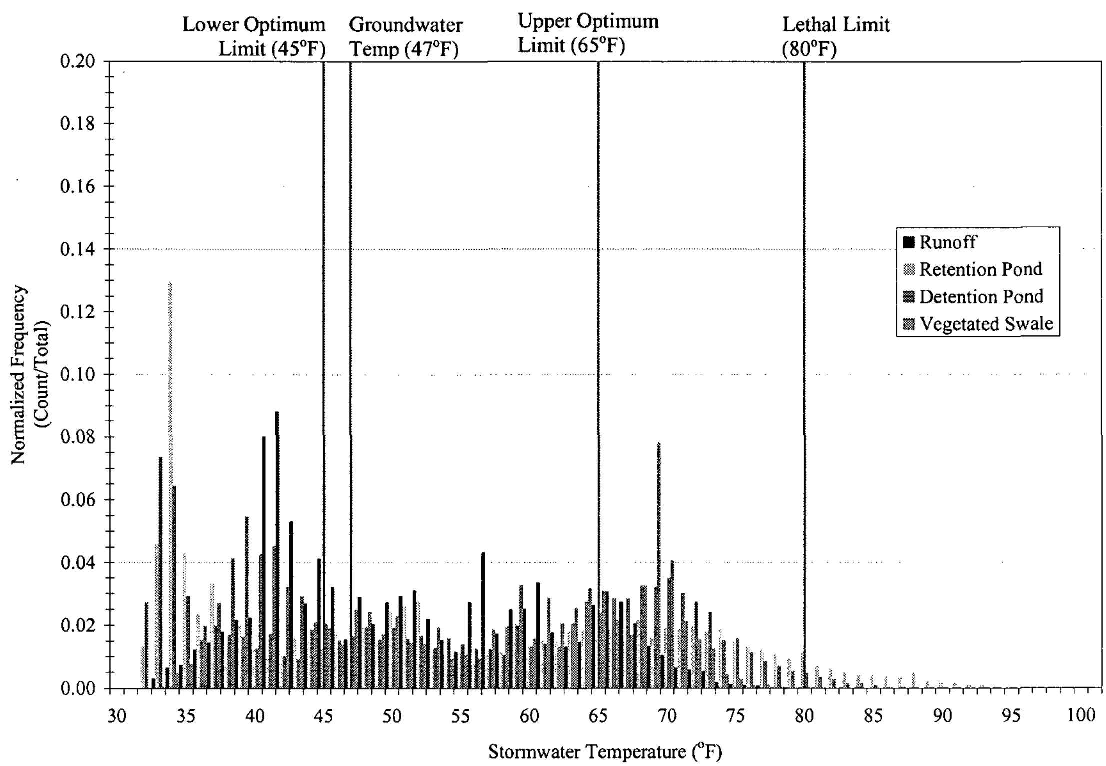


Figure 25: Frequency Distribution for Real-Time Temperatures

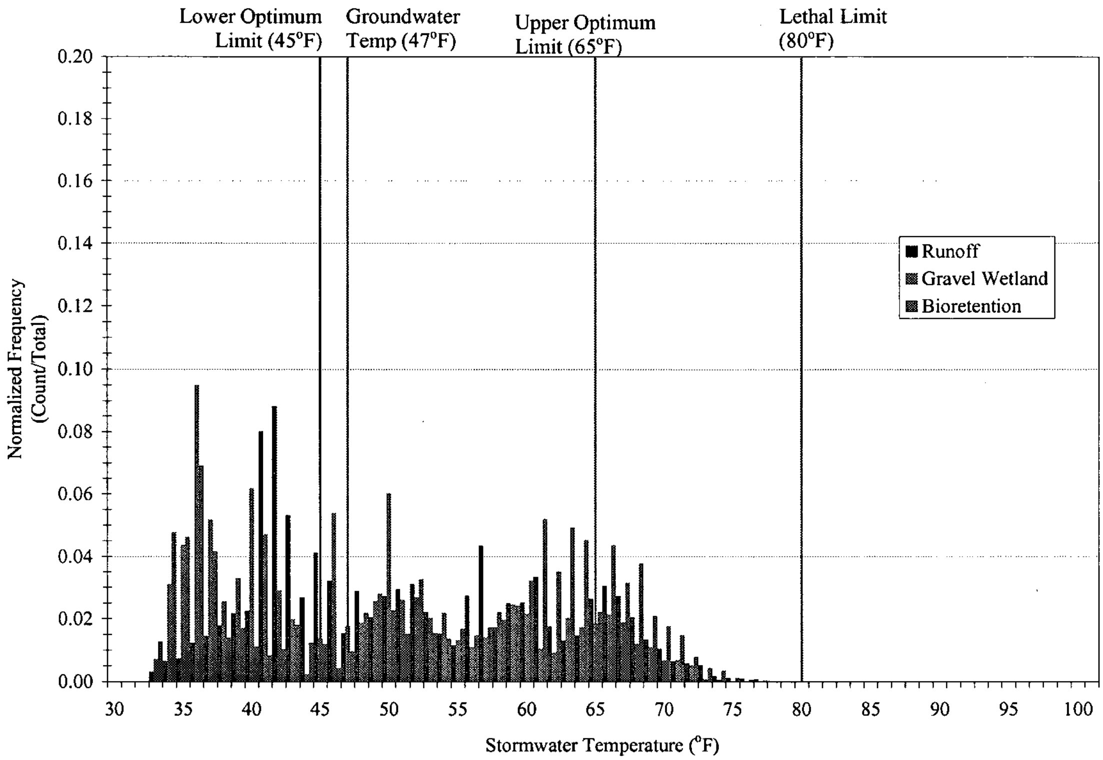


Figure 26: Frequency Distribution for Real-Time Temperatures

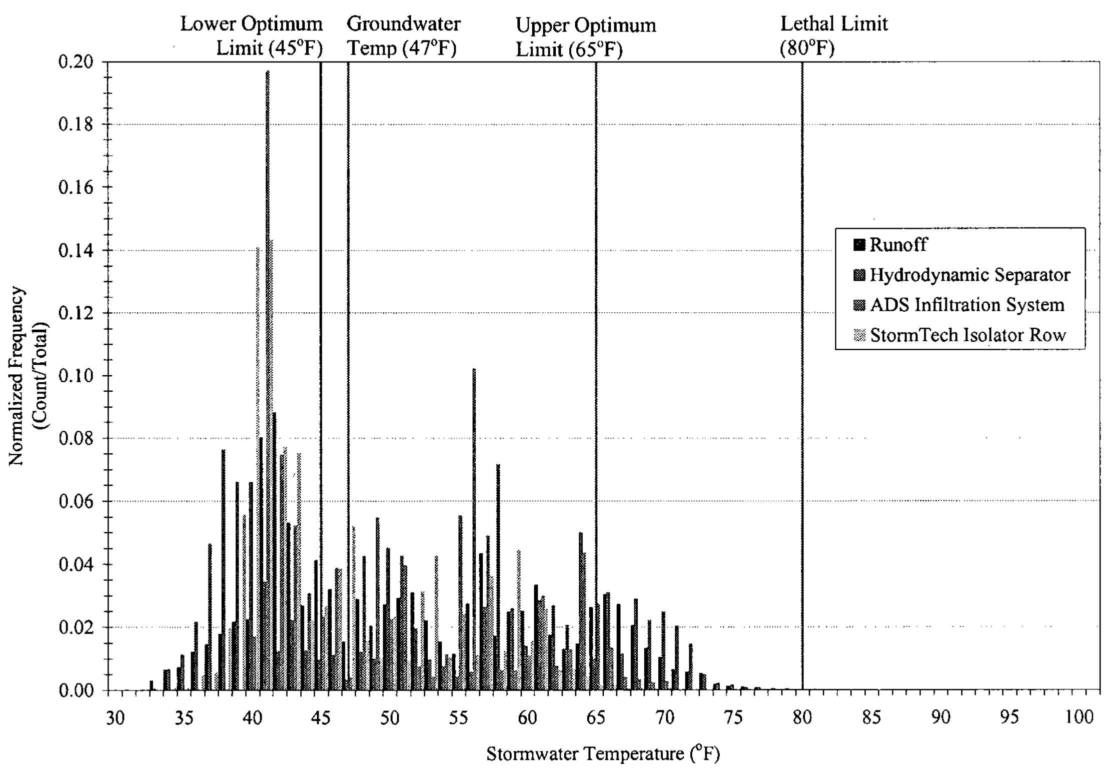


Figure 27: Conventional System Treatments (Annual)

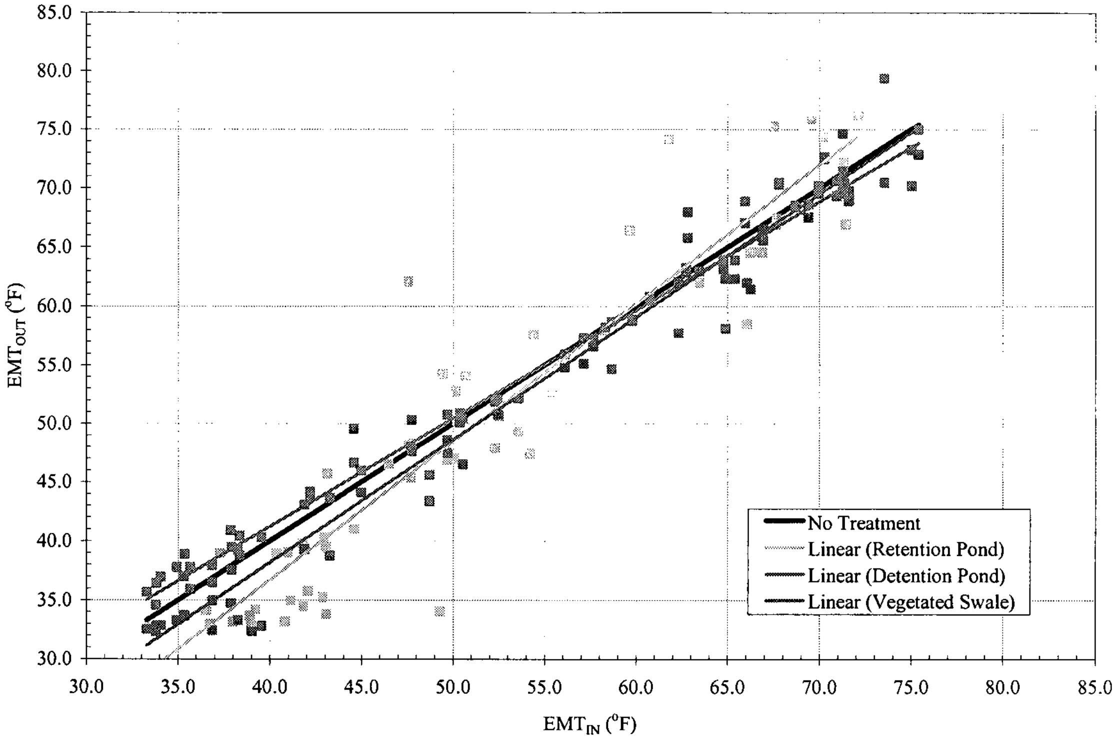


Figure 28: LID System Treatments (Annual)

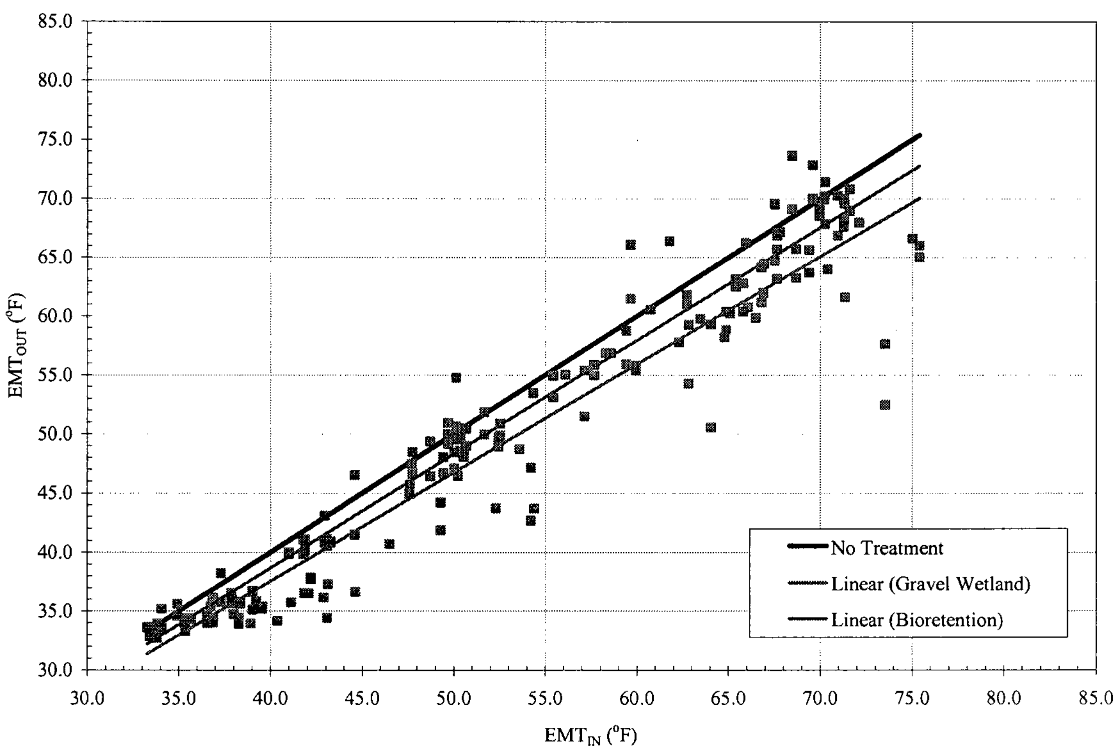


Figure 29: Manufactured Systems Treatment (Annual)

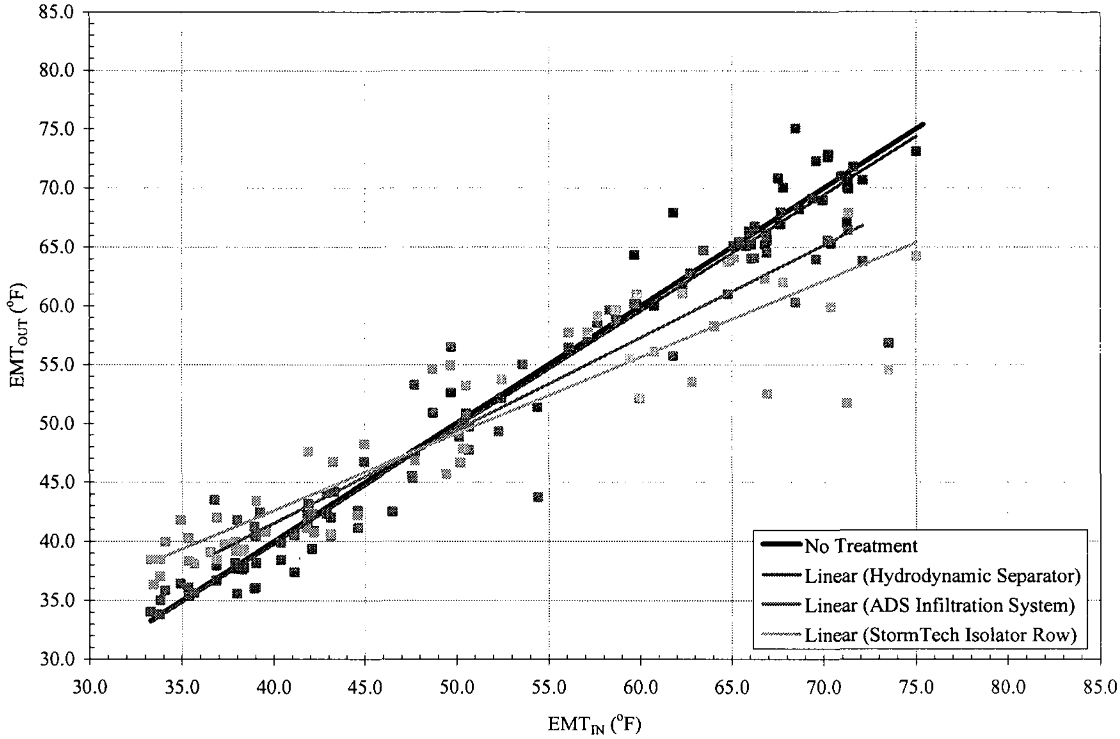


Table 17: Linear Regressions of Annual Treatments

System	Equation	R^2
Retention Pond	Y = -10.2 + 1.2X	0.88
Detention Pond	Y = -3.6 + 1.0X	0.97
Gravel Wetland	Y = 0.8 + 0.9X	0.93
Bioretention	Y = 0.2 + 1.0X	0.94
Vegetated Swale	Y = 4.4 + 0.9X	0.99
HDS	Y = 0.3 + 1.0X	0.96
ADS	Y = 10.1 + 0.8X	0.88
STIR	Y = 16.6 + 0.6X	0.83

Figure 30: Conventional Systems Treatment (Summer)

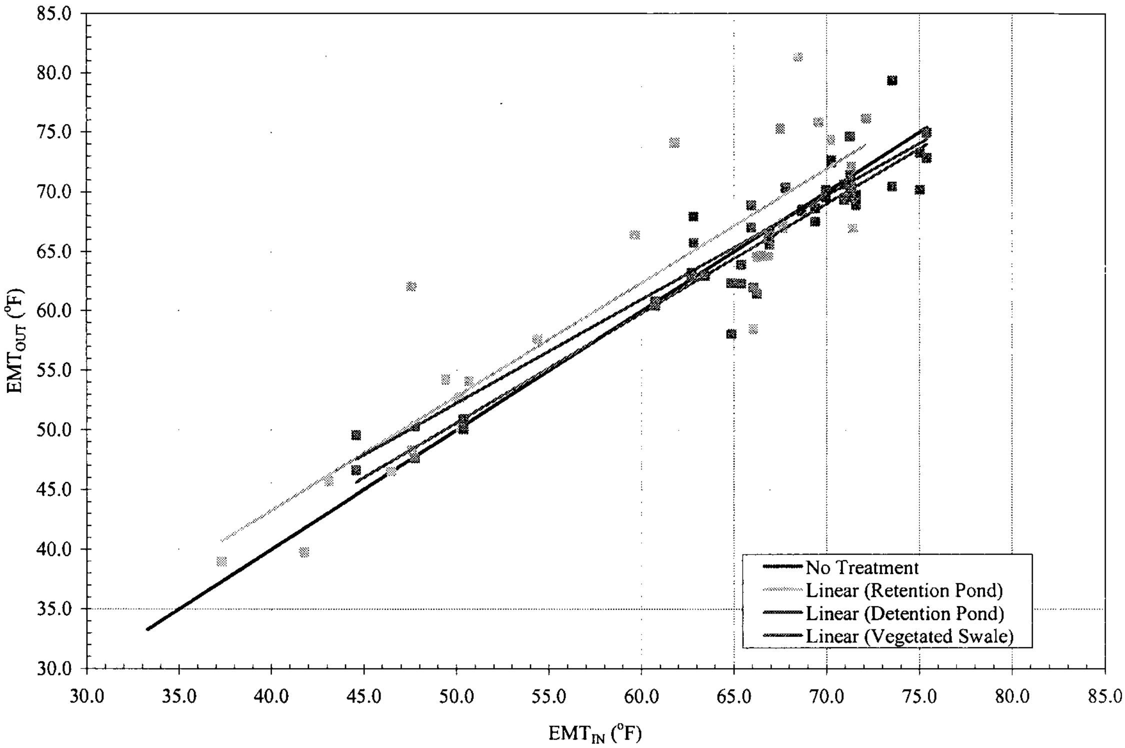


Figure 31: LID Systems Treatment (Summer)

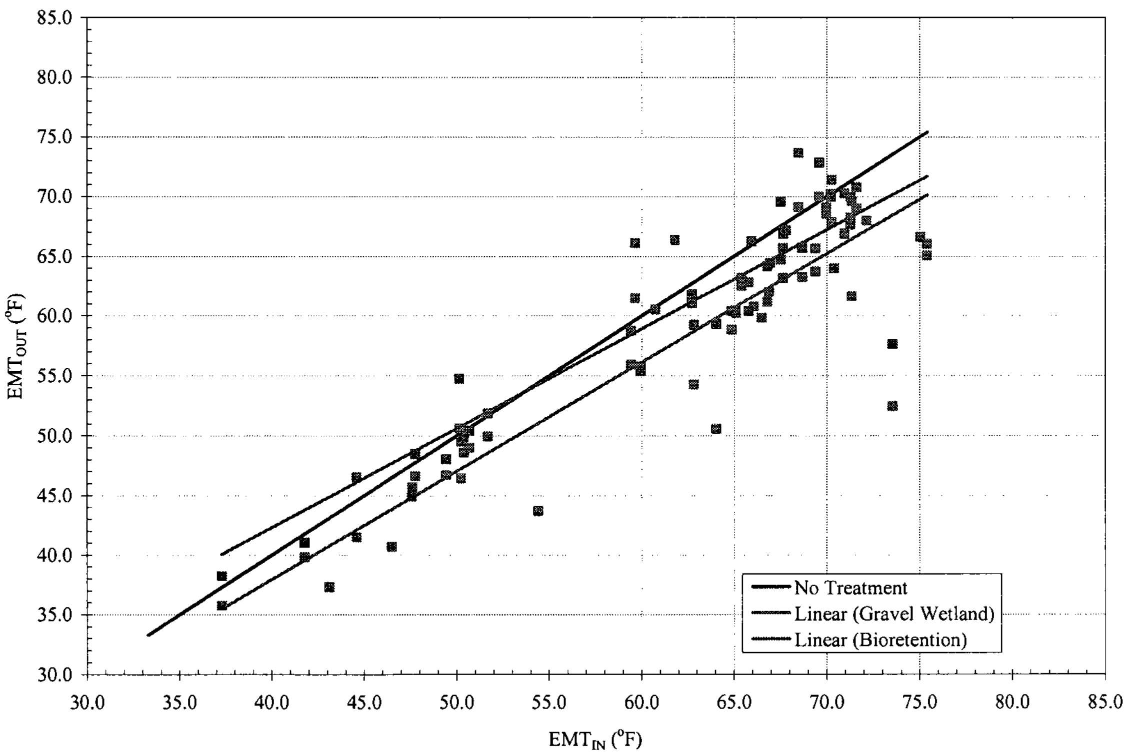


Figure 32: Manufactured Systems Treatment (Summer)

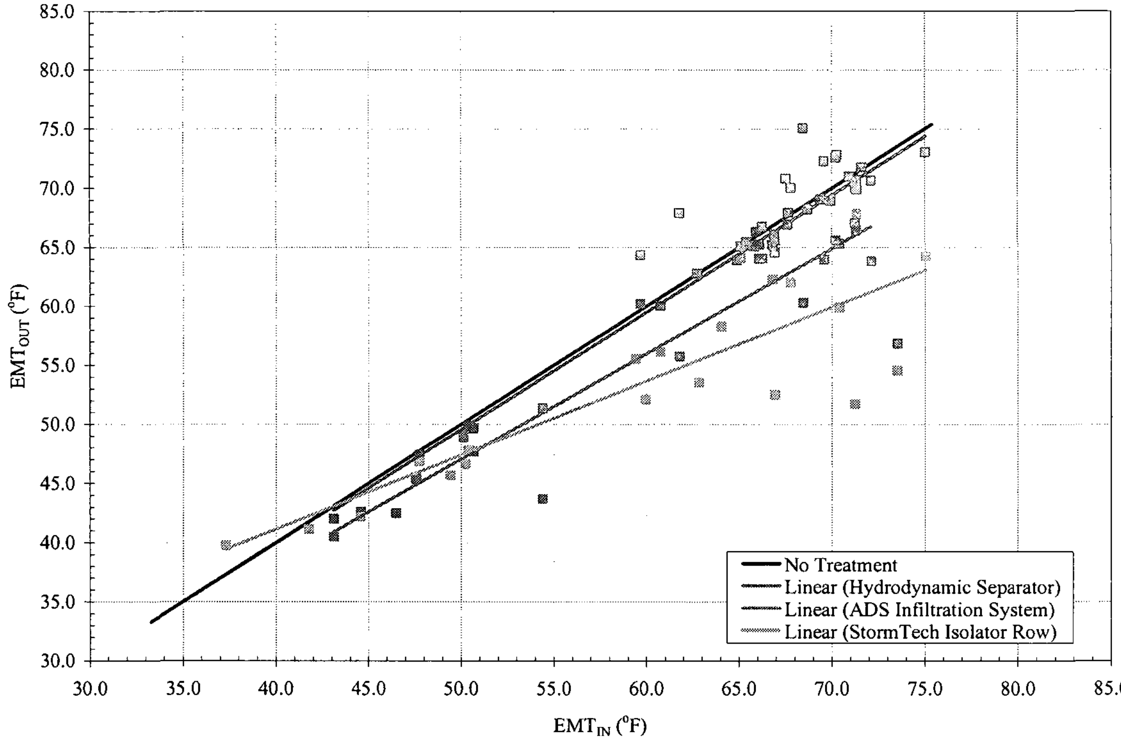


Table 18: Linear Regressions of Summer Treatments

System	Equation	R^2
Retention Pond	Y = 5.1 + 1.0X	0.80
Detention Pond	Y = 8.6 + 0.9X	0.86
Gravel Wetland	Y =1.5 + 0.9X	0.85
Bioretention	Y = 9.1 + 0.8X	0.82
Vegetated Swale	Y = 4.5 + 0.9X	0.93
HDS	Y = -0.1 + 1.0X	0.86
ADS	Y = 2.5 + 0.9X	0.91
STIR	Y = 16.1 + 0.6X	0.75

Figure 33: Conventional Systems Treatment (Winter)

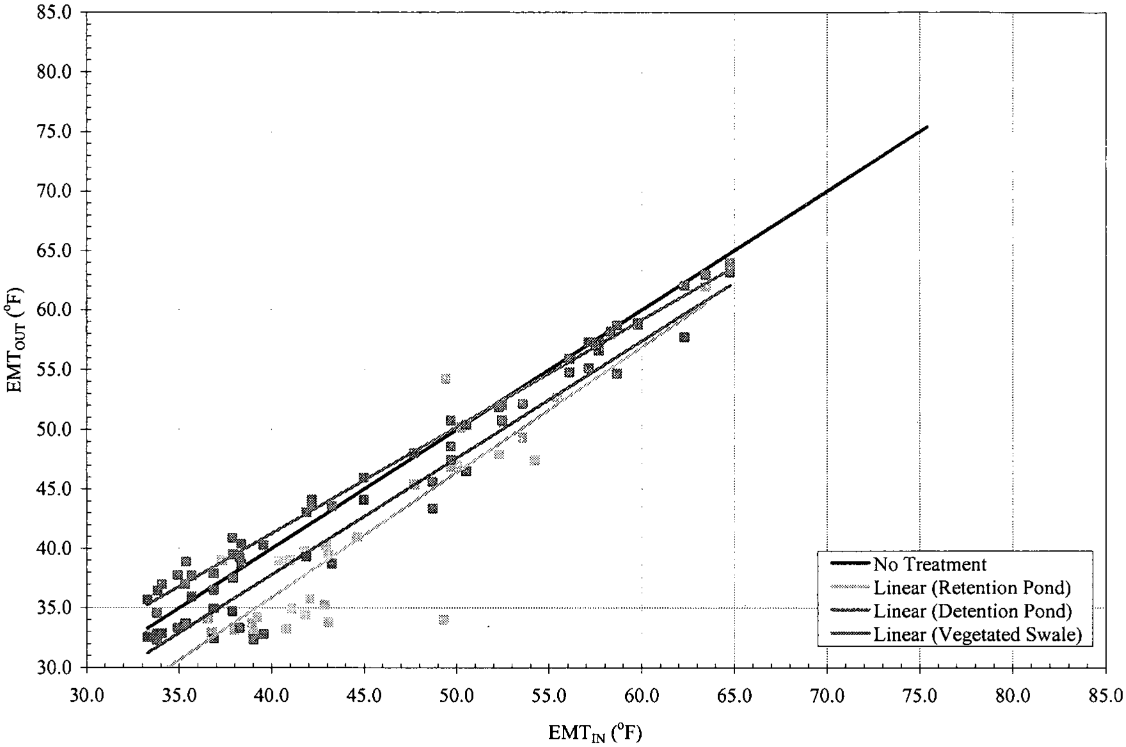


Figure 34: LID Systems Treatment (Winter)

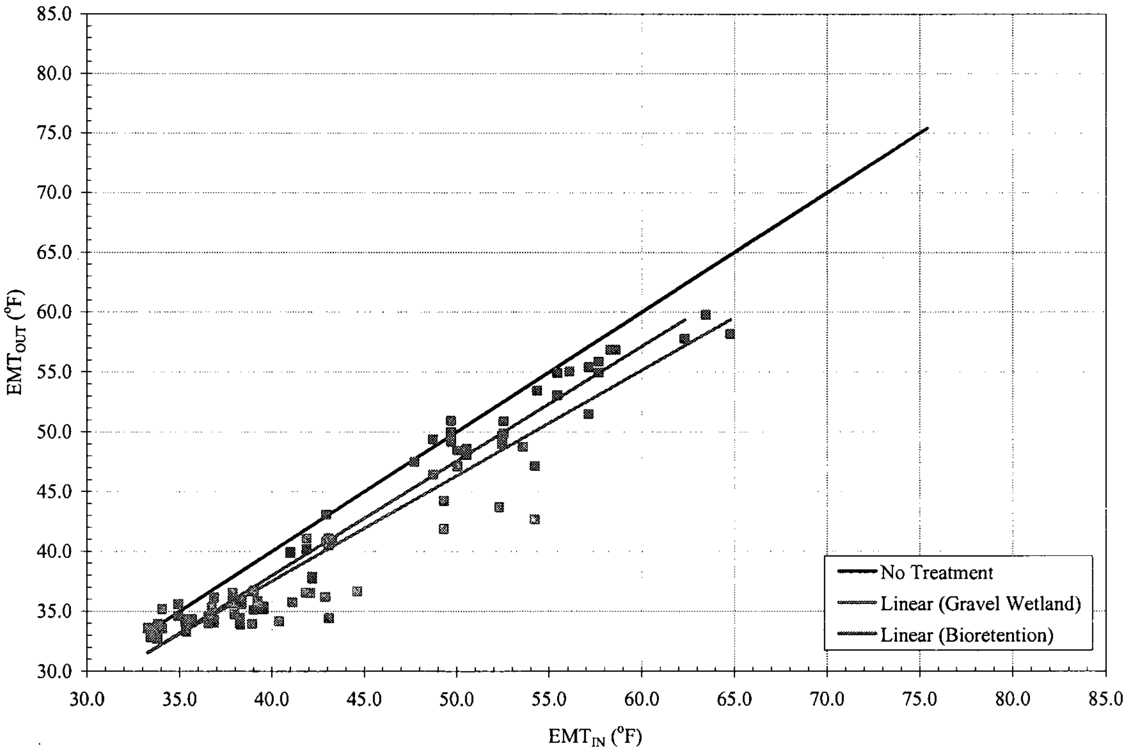


Figure 35: Manufactured Systems Treatment (Winter)

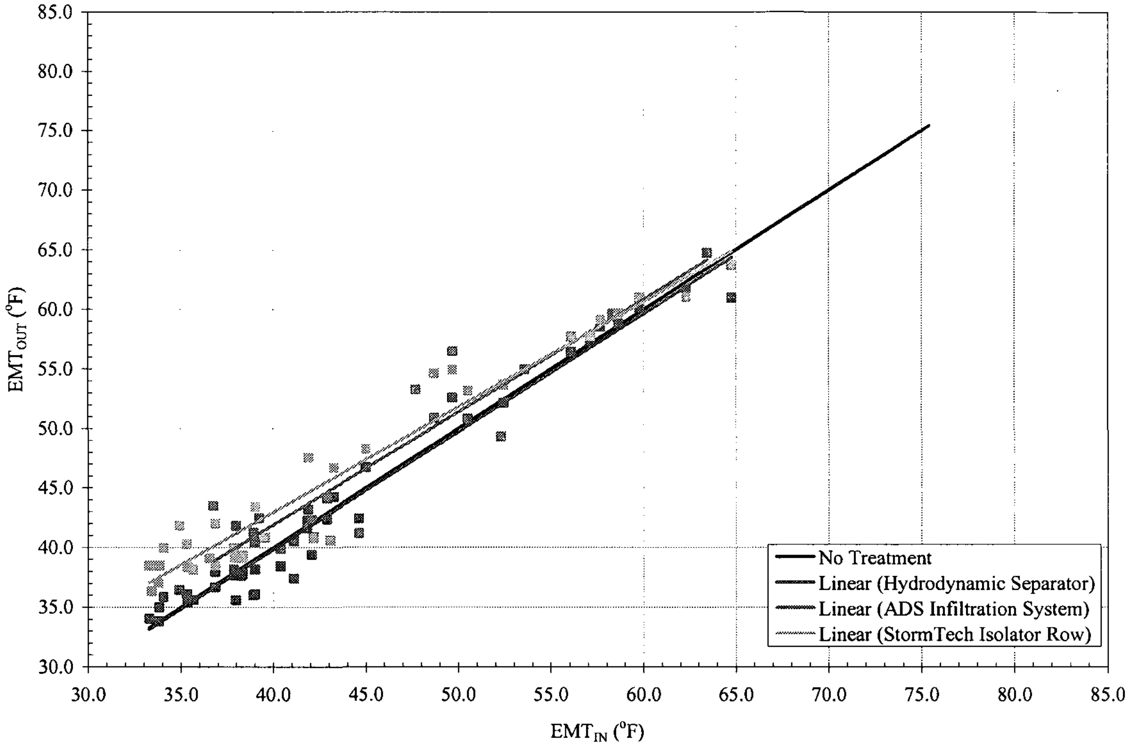


Table 19: Linear Regressions of Winter Treatments

System	Equation	R^2
Retention Pond	Y = -6.1 + 1.1X	0.82
Detention Pond	Y = -1.53 + 1.0X	0.96
Gravel Wetland	Y = 2.2 + 0.9X	0.90
Bioretention	Y = -0.3 + 1.0X	0.95
Vegetated Swale	Y = 5.5 + 0.9X	0.99
HDS	Y = 0.2 + 1.0X	0.97
ADS	Y = 4.0 + 0.9X	0.86
STIR	Y = 7.6 + 0.9X	0.95

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APPENDICES

APPENDIX A

STORM CHARACTERISTICS

Table 20: Storm Characteristics

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
1	1	01/13/2005	2,365	N/A	0.00	0.00	3,871	46.4	42.9
1a	2	02/04/2005	5,070	N/A	0.00	0.00	202	43.7	40.8
2	3	02/09/2005	3,325	N/A	0.00	0.00	814	43.0	38.0
2a	4	02/14/2005	4,595	N/A	0.00	0.00	906	42.4	38.9
3	5	03/07/2005	2,110	0.85	0.01	0.80	429	41.7	39.0
3a	6	03/13/2005	21,595	0.25	0.01	0.14	261	45.0	41.1
4	7	03/28/2005	5,190	N/A	0.00	0.00	1,408	44.6	40.4
5	8	04/02/2005	2,985	1.06	0.05	1.71	1,305	45.7	43.1
5a	9	04/20/2005	855	8.16	0.04	0.58	350	59.0	54.4
6	10	08/12/2005	855	N/A	0.00	0.00	2,420	76.6	72.1
6a	11	08/14/2005	985	N/A	0.00	0.00	1,213	77.4	71.3
7	12	09/15/2005	3,325	N/A	0.00	0.00	4,767	75.7	71.6
7a	13	09/20/2005	960	N/A	0.00	0.00	114	68.5	66.3
8	14	09/26/2005	290	N/A	0.09	0.58	1,778	67.5	66.9
8a	15	09/29/2005	145	1.23	0.13	0.38	2,298	66.6	66.1
9	16	10/08/2005	2,130	8.31	0.10	5.00	3,792	73.2	63.5
9a	17	10/10/2005	1,195	1.51	0.05	0.94	1,636	62.1	58.3
10	18	10/22/2005	1,260	4.52	0.06	0.90	1,365	60.4	49.7
11	19	11/06/2005	1,240	14.52	0.04	0.29	1,205	58.3	53.6
11a	20	11/09/2005	925	2.66	0.06	0.94	1,527	55.9	47.7
12	21	11/30/2005	1,140	1.10	0.03	0.69	1,057	54.0	52.3
13	22	12/16/2005	4,680	5.79	0.06	1.38	1,086	49.5	36.8
13a	23	12/23/2005	5,400	7.26	0.05	1.09	1,377	47.3	39.2

[8] Rainfall conditions that triggered a measurable flow event. Dates labeled "N/A" report missing rainfall data before the storm.

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
14	24	01/11/2006	6,060	2.37	0.05	0.59	1,984	46.2	42.1
14a	25	01/17/2006	2,325	N/A	0.00	0.00	2,309	45.5	41.8
15	26	03/12/2006	4,245	2.19	0.03	0.99	1,139	48.9	44.6
16	27	04/01/2006	9,025	18.11	0.06	2.29	2,728	58.8	46.5
17	28	04/23/2006	2,800	9.69	0.02	0.78	1,228	50.0	47.6
17a	29	04/28/2006	95	N/A	0.00	0.00	456	47.8	47.6
18	30	05/01/2006	2,905	N/A	0.04	2.43	1,923	53.4	50.7
18a	31	05/09/2006	17,855	5.89	0.12	11.25	5,817	59.9	50.1
19	32	06/01/2006	18,515	5.93	0.41	6.89	14,887	79.0	59.7
20	33	06/20/2006	16,395	5.27	0.09	1.08	3,348	75.9	61.8
20a	34	07/11/2006	3,490	11.69	0.15	2.28	9,755	78.3	70.2
21	35	07/21/2006	2,875	8.18	0.13	0.95	4,951	81.0	69.6
21a	36	07/28/2006	5,000	5.47	0.07	0.38	4,044	84.2	68.5
22	37	08/14/2006	1,385	N/A	0.00	0.00	15,571	72.9	67.5
22a	38	08/20/2006	1,860	N/A	0.00	0.00	9,203	71.6	67.7
23	39	09/03/2006	810	N/A	0.04	0.48	4,070	70.2	67.6
24	40	09/14/2006	380	N/A	0.00	0.00	738	67.8	66.5
24a	41	09/19/2006	430	N/A	0.00	0.00	2,438	73.0	71.4
25	42	10/17/2006	960	4.85	0.01	0.36	661	57.9	54.3
25a	43	10/20/2006	1,135	1.69	0.05	0.70	1,778	61.0	58.6
26	44	11/08/2006	1,860	N/A	0.05	2.12	2,181	55.2	52.5
26a	45	11/12/2006	8,195	3.46	0.10	2.95	4,882	61.0	55.4
27	46	12/01/2006	1,235	2.19	0.09	1.09	3,783	55.4	50.0
27a	47	12/13/2006	225	11.75	0.01	0.05	328	52.5	49.3
28	48	12/22/2006	1,200	9.09	0.03	1.21	1,576	50.0	43.1
28a	49	12/25/2006	1,060	2.40	0.02	0.62	933	54.3	41.0

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
29	50	01/05/2007	1,200	3.51	0.06	0.66	1,271	56.8	54.2
29a	51	01/08/2007	960	1.39	0.00	0.00	688	49.1	42.9
30	52	03/02/2007	1,900	12.66	0.05	1.55	558	41.0	33.4
31	53	03/10/2007	1,075	7.81	0.00	0.00	116	45.7	36.6
31a	54	03/15/2007	460	N/A	0.00	0.00	10	44.4	43.1
32	55	04/12/2007	1,530	4.82	0.02	0.84	214	45.5	37.3
32a	56	04/15/2007	4,520	1.80	0.07	6.49	2,830	48.0	41.8
33	57	04/27/2007	490	8.06	0.02	0.54	328	51.8	50.2
33a	58	04/29/2007	260	1.27	0.01	0.11	40	49.8	49.4
34	59	05/11/2007	180	10.74	0.05	0.26	2,029	65.3	64.1
34a	60	05/15/2007	7,945	3.92	0.01	0.04	2,984	59.9	51.7
35	61	06/01/2007	105	0.26	0.04	0.07	332	60.4	59.4
35	62	06/02/2007	975	1.10	0.02	0.10	32	62.8	59.9
36	63	07/04/2007	435	21.45	0.04	0.55	839	67.5	66.8
36a	64	07/06/2007	110	1.44	0.03	0.11	243	73.2	70.4
37	65	09/09/2007	3,525	22.19	0.11	0.48	4,604	70.9	65.8
37a	66	09/15/2007	365	3.49	0.03	0.23	261	65.1	65.1
38	67	09/27/2007	370	12.48	0.13	0.47	3,903	72.3	71.3
39	68	10/09/2007	285	1.52	0.03	0.19	546	60.3	59.8
39a	69	10/11/2007	1,450	1.54	0.10	1.26	4,252	62.1	58.7
40	70	10/19/2007	555	7.00	0.06	0.93	2,171	65.7	64.8
41	71	10/27/2007	1,040	1.70	0.04	0.72	502	61.3	56.1
42	72	11/03/2007	500	6.27	0.03	1.10	491	55.4	45.0
43	73	11/06/2007	560	2.36	0.06	0.71	1,410	56.1	50.5
43a	74	11/13/2007	125	5.60	0.01	0.08	11	53.6	48.7
44	75	11/26/2007	1,410	3.64	0.04	0.87	379	50.5	41.9
45	76	12/23/2007	475	11.67	0.09	0.33	2,090	45.1	36.9
46	77	12/29/2007	695	0.47	0.03	0.42	211	46.0	34.9

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
47	78	01/11/2008	730	1.61	0.06	0.69	708	45.5	35.3
48	79	01/18/2008	345	2.66	0.04	0.59	328	45.7	34.1
49	80	02/01/2008	1,265	2.52	0.01	0.01	502	43.7	33.3
50	81	02/05/2008	2,195	2.74	0.08	0.37	308	43.9	33.8
51	82	02/13/2008	3,580	3.22	0.61	0.69	724	42.1	33.8
51a	83	02/17/2008	4,140	3.34	0.03	0.49	449	42.8	38.3
52	84	02/25/2008	4,980	2.37	0.01	0.14	11	42.6	39.6
53	85	03/04/2008	3,840	2.94	0.07	0.93	958	42.4	35.4
54	86	03/07/2008	1,380	2.49	0.02	0.35	300	41.7	35.7
55	87	03/08/2008	2,275	0.38	0.05	1.21	974	41.0	36.9
55a	88	03/12/2008	4,920	3.58	0.01	0.66	214	42.4	38.4
56	89	03/19/2008	2,520	2.75	0.03	0.91	505	42.3	37.9
56a	90	03/28/2008	13,020	7.86	0.08	1.55	982	49.1	42.2
57	91	04/10/2008	4,020	6.39	0.02	0.28	191	46.8	44.6
58	92	04/27/2008	3,900	15.10	0.06	2.74	2,266	53.8	50.4
58a	93	05/03/2008	2,280	3.00	0.04	0.55	1,340	49.6	47.8
59	94	05/27/2008	270	5.59	0.01	0.01	583	78.4	73.5
60	95	05/30/2008	1,785	3.95	0.06	0.13	1,257	71.2	62.8
61	96	06/04/2008	3,780	3.73	0.04	1.01	1,050	65.5	60.7
62	97	06/10/2008	345	3.84	0.03	0.21	589	72.3	71.3
63	98	06/14/2008	4,450	4.01	0.11	1.71	5,918	72.7	66.9
64	99	06/20/2008	560	2.22	0.09	0.20	3,358	78.8	75.0
64a	100	06/22/2008	3,600	1.86	0.08	0.77	3,278	74.8	67.8
65	101	07/17/2008	5,460	4.37	0.17	2.58	17,731	83.1	70.3
66	102	07/23/2008	2,280	2.10	0.21	3.84	17,354	73.8	71.3
66a	103	07/27/2008	1,500	2.18	0.08	0.61	10,281	77.9	75.4
67	104	08/02/2008	840	1.95	0.08	0.38	3,040	74.3	71.0

Event Label	Event No.	Date	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
Full Record	Full Record								EMT
		mm/dd/yyyy	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
68	105	08/03/2008	360	0.55	0.25	0.65	11,751	73.0	71.6
68a	106	08/06/2008	4,020	2.60	0.11	2.56	3,897	70.3	65.9
69	107	09/06/2008	1,860	17.84	0.14	4.40	6,727	76.3	70.0
70	108	09/09/2008	840	2.31	0.13	0.38	2,832	70.3	69.4
70a	109	09/12/2008	660	3.11	0.01	0.15	91	66.2	65.4
71	110	09/14/2008	780	1.28	0.04	0.39	886	70.0	68.7
71a	111	09/21/2008	240	7.48	0.03	0.09	272	65.1	64.9
72	112	09/26/2008	4,615	4.32	0.11	3.38	4,513	67.6	62.7
72a	113	10/09/2008	540	2.98	0.02	0.22	380	61.3	57.7
73	114	10/16/2008	780	7.06	0.10	0.44	2,726	63.0	62.3
74	115	10/21/2008	1,000	4.89	0.03	0.30	483	60.1	49.7
74a	116	10/25/2008	705	3.60	0.20	1.26	6,408	59.4	57.1
75	117	11/13/2008	4,220	2.15	0.05	1.18	582	57.7	52.5
75a	118	11/24/2008	1,510	8.62	0.05	1.96	1,163	52.5	43.3
76	119	12/10/2008	4,260	8.47	0.03	1.99	1,127	50.4	37.9
76a	120	12/24/2008	2,520	2.84	0.01	0.23	409	47.7	39.0

	Storm Duration	Antecedent Dry[8]	Peak Intensity	Rainfall Depth	Peak Flow	Peak Temperature	Runoff
							EMT
	minutes	days	in/5-min	inches	gal/min	Fahrenheit	Fahrenheit
Minimum	95	0.25	0.00	0.00	10	41.0	33.3
25th Percentile	702	2.17	0.01	0.14	476	47.6	41.9
Median	1,398	3.50	0.04	0.57	1,209	58.6	52.4
75th Percentile	3,645	7.01	0.08	1.08	2,870	70.1	66.0
Maximum	21,595	22.19	0.61	11.25	17,731	84.2	75.4
Mean	2,730	5.06	0.06	0.98	2,422	58.8	53.5
Standard Deviation	3,647	4.53	0.08	1.53	3,408	12.1	12.7

APPENDIX B

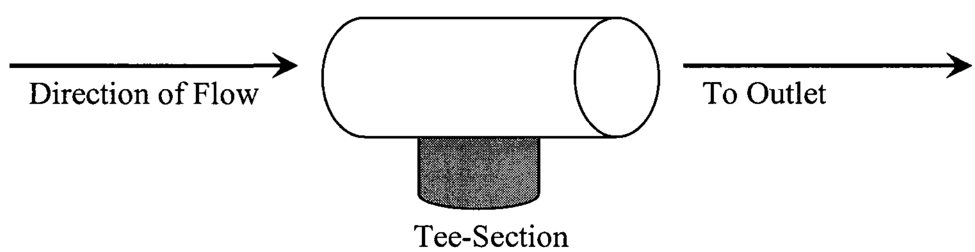
POROUS ASPHALT

Introduction

The Porous Asphalt data was omitted from the complete report because of concerns over the validity of the data gathered. EMTs calculated from storms occurring in September 2008 reached 90°F and even above 100°F. These storms are removed from the analysis below, under the assumption of a faulty probe. This error showed itself prominently during the September 2008 storms, but concerns of the validity of the remaining dataset prompted the decision to remove the Porous Asphalt system from the full report.

In an effort to locate the source of the error, two hypotheses were presented; the first that the temperature probe was faulty for just the September 2008 storms, and by the regular maintenance of the probes, was correctly recalibrated resulting in an errorless dataset.

The second hypothesis is that the monitoring set up was at fault. The temperature probe for the effluent from the Porous Asphalt sits in the tee section of pipe just before the end of the outlet. The tee is positioned so that two of the arms are inline with the outlet pipe, and the third arm, pointing downward, acting as a sump. The tee section is used to create a permanent pool of water for the probes to sit in so that they do not dry out, which can cause malfunctions in the probes.



The concern is that the low flows experienced within the Porous Asphalt effluent pipe are not large enough to mix the water properly. The tee section is exposed to the air, and as with the rest of the outlet pipe, is made of HDPE pipe, which is black. This exposure can add a great deal of thermal energy to the pool of water in the tee section. Therefore, if the flow through the effluent pipe is not large enough, then perhaps the readings of the effluent temperature for the Porous Asphalt system are not reflective of the system, but instead of the monitoring design.

An experiment was conducted with a temperature probe placed approximately 7 to 9 feet into the effluent pipe to demonstrate this monitoring issue. The data collected from the upstream probe appeared to be roughly similar to the data collected from the probe in the tee. However, this test was conducted in November; the air temperatures were not warm enough to address the concerns over the data. Further experiments, of the same sort as was done in November, or properly modified to describe the influence of the permanent pool of water on the temperature readings of the effluent flow from the Porous Asphalt, should be conducted in at least the warmer, summer months, if not for a continuous year.

The Porous Asphalt data is presented here to show what the data collected indicates about the thermal performance of the system as a treatment of thermal pollution. The full report compares influent stormwater temperatures, measured at the distribution box, to effluent stormwater temperatures, measured at a sampling gallery. The Porous Asphalt does not receive influent stormwater from the distribution box. Instead, the Porous Asphalt is a hydrologically separate system from the others. The rain that falls on the Porous Asphalt goes filters into the sub-base of the Porous Asphalt and does not flow to the distribution box. However, for the sake of consistency, the Porous Asphalt system is compared to the Runoff, but not an influent to effluent relationship.

System Description

Porous asphalt is an extremely effective approach to stormwater management. Unlike retention ponds, porous asphalt systems do not require large amounts of additional space. Rainfall drains through pavement and directly infiltrates the subsurface. This significantly reduces runoff volume and peak flows, decreases its summer temperature, improves water quality, and essentially eliminates the impervious surface. It also speeds snow and ice melt, reducing the salt required for winter maintenance. The porous asphalt design tested at UNHSC is distinctive in its use of coarse sand as a sub base filter course, a refinement that enhances its effectiveness in improving water quality.

Installed in 2004, the lot was designed to manage the WQV, CPV, and the Q100. A gravel edge with curbing prevents water and sediment from washing onto the porous lot's surface and prematurely clogging the system. UNHSC's current design of the Porous Asphalt system consists of four layers.

The top is a four-inch layer of porous asphalt. Sand particles smaller than two millimeters were removed from the mix to create pavement with an 18 to 20 percent void space. The second layer is a four-inch choker course consisting of 3/4 inch crushed stone, which allows runoff to pass into the next layer and offers structural support. The third layer consists of 24 inches of poorly graded sand, or "bank run gravel," which serves as a filter course. The fourth layer is 21 inches of crushed stone, with a six-inch diameter, elevated sub drain. This layer serves as an infiltration reservoir; its thickness protects against freezing and thawing, and makes it possible to locate this system in group "C" soils (sandy clay loam with low infiltration rates). The system is lined on the bottom and sides with a non-woven geotextile fabric to prevent influx of fines.

Time Series Analysis

The data for the Porous Asphalt, while containing some large gaps, illustrated on the graph (Figure 36) as the longer than usual straight lines, still shows some obvious trends. The Porous Asphalt appears to diminish the peaks of the EMTs of the same storms from the Runoff data, indicating a moderation of the stormwater temperature. The EMT also peaks during the summer months above the UOL of 65°F for coldwater streams. While the Porous Asphalt system appears to produce a "smoother" curve of EMTs, it should be noted that from this analysis, the data appears to be predominantly warmer than the data creating the Runoff curves.

Annual Cumulative Distributions

The cumulative distribution of the EMTs, displayed in Figure 37, is calculated as a nonexceedance probability of an EMT. The Porous Asphalt has cooler stormwater temperatures than the Runoff. This implies that the infiltration of the stormwater runoff into the Porous Asphalt sub base, is keeping the stormwater runoff closer to the average groundwater temperature (47°F) of New Hampshire, than the Runoff is able with its reinforced concrete pipes (RCPs).

Seasonal Cumulative Distributions

During the summer months, the Porous Asphalt exceeds the UOL only 39% of the time, while the Runoff system exceeds the UOL (65°F) 58% of the time, with neither system ever exceeding the Lethal Limit (LL) of 85°F. This exhibits the ability of the

Porous Asphalt system to maintain effluent temperatures below the UOL more consistently than the Runoff.

The winter CDF shows that the Porous Asphalt has warmer EMTs than the Runoff system, indicating that the Porous Asphalt system is able to moderate the colder temperatures more effectively than the Runoff. Both the stormwater sewer system and the Porous Asphalt systems are deep systems, with smaller surface areas than the conventional systems. The stormwater sewer system is most likely larger in mass than the Porous Asphalt system, but because the Porous Asphalt system has a longer travel time, the system can moderate the temperatures longer than the Runoff is able. However, during the winter, a deicer is in place at the tee section to keep the probes from freezing, giving false temperature reading during the colder temperatures.

Annual Quartile Assessment

Examination of the full data set shows the Porous Asphalt to have a lower median EMT of 48.9°F compared to the median Runoff EMT of 52.4°F. Although the Porous Asphalt EMTs has as much variability as the Runoff system, the data in Figure 38 shows that the Porous Asphalt has both a median and 25th percentile value pretty close to the Lower Optimum Limit (LOL) of 45°F and the average annual groundwater temperature of 47°F. The Porous Asphalt, median EMT, and the 25th percentile EMT at 44.1°F are closer together than the corresponding values of the Runoff shown in Table 22. This indicates, again, that the Porous Asphalt is more effectively bringing the stormwater runoff temperatures closer to that of the average annual groundwater temperature than the Runoff system. With coldwater streams often being fed by groundwater, this is an important variable to consider.

Seasonal Quartile Assessment

During the summer months, the median EMT for the Porous Asphalt is 55.4°F, which falls in the optimum zone for coldwater streams. The Runoff data has a median EMT of 66.2°F, which brings it into the stress zone for coldwater streams. Both systems have their 25th percentile above the LOL, and stay within the optimum zone, but the Runoff has a 25th percentile value of 54.2°F, a value that is 6.2°F higher than the Porous Asphalt's 25th percentile. These observations indicate that the Porous Asphalt is able to produce cooler EMTs more often than the Runoff.

The winter quartile assessment shows that the Porous Asphalt has a median EMT of 46.4°F, a slightly higher value than the Runoff, which has an EMT of 42.5°F. Although the Porous Asphalt EMT is higher than the Runoff, it is above the LOL, while the Runoff system falls below the average groundwater of 47°F. The median winter EMT of the Porous Asphalt is also very close to the groundwater temperature. One observation of note that contradicts the previous statements of the Porous Asphalt being a generally cooler system is the maximum winter EMT is 68.8°F, which is above the UOL, and into the stress zone for coldwater streams. The Runoff system manages to keep, although only just, the EMT of the stormwater runoff from breaching that limit, with a maximum of 64.8°F.

Frequency Distribution

From the frequency distribution chart (Figure 39), the effluent flow from the Porous Asphalt has a large number of its temperatures between 45°F and 54°F. These temperatures fall within the optimum zone for coldwater streams. In contrast to the Porous Asphalt, the Runoff system has a large number of its effluent temperatures at 41°F and 42°F, which are below the LOL. The Porous Asphalt generally has a lower number of effluent temperatures above the UOL of 65°F than the Runoff system. However, above 70°F, the Porous Asphalt experiences those temperatures more frequently than the Runoff. In addition to this spike of temperatures occurring at the higher end of the spectrum, there is a spike of temperatures occurring at 35°F in the Porous Asphalt. This spike can be attributed to the limit of the temperature of water itself. Water, freezing at 32°F, does not flow, therefore the high count at 35°F in the Porous Asphalt is most likely the temperature at which, more consistently than the rest, and the stormwater is allowed to flow at during the winter months. In addition, this increase in frequencies of temperatures at the lower end can be attributed to the deicer present during the colder winter months.

Figure 36: Time Series Analysis

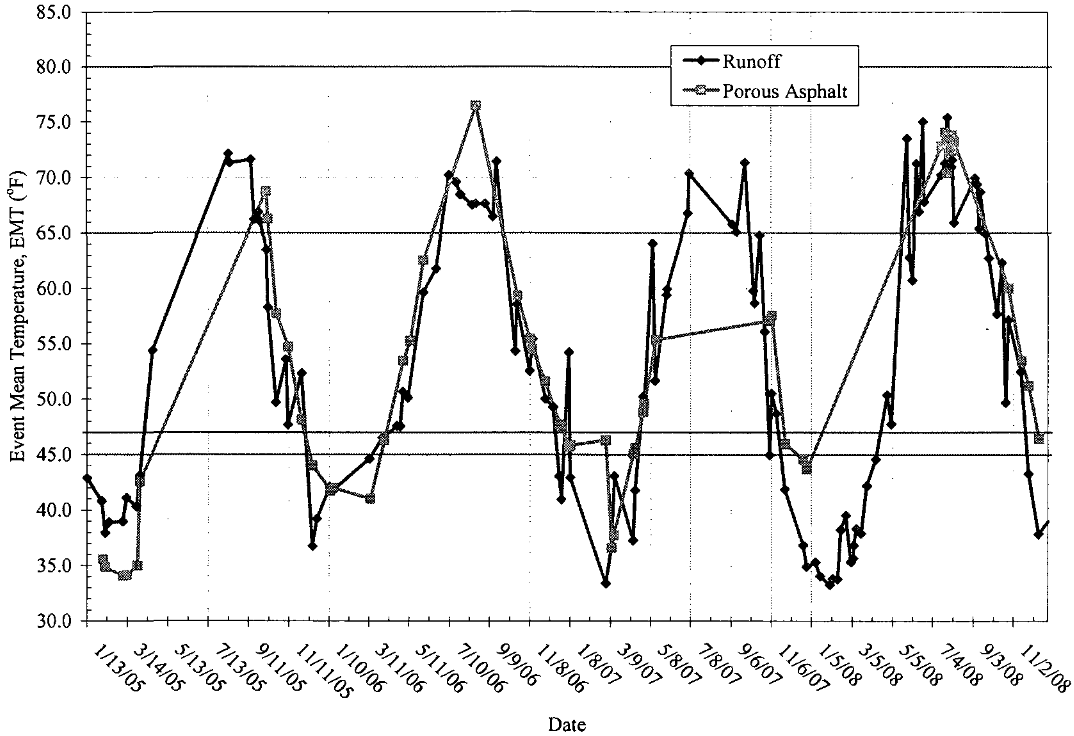


Figure 37: Cumulative Distribution

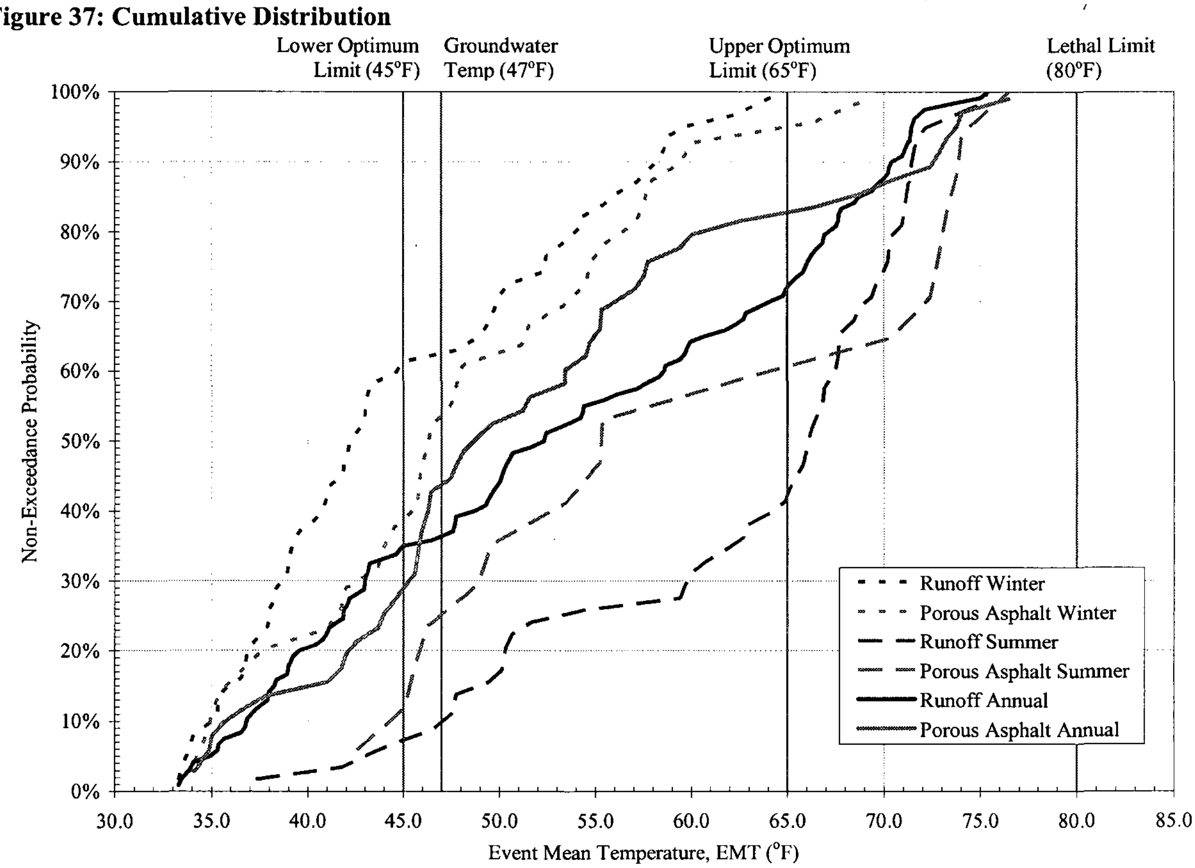


Table 21: Porous Asphalt CDF Summary

	%Exceedance	%Exceedance
	Upper Optimum Limit (65°F)	
System	Annual	Summer
Runoff	27.5%	58.0%
Porous Asphalt	17.5%	39.0%

Figure 38: Box and Whisker

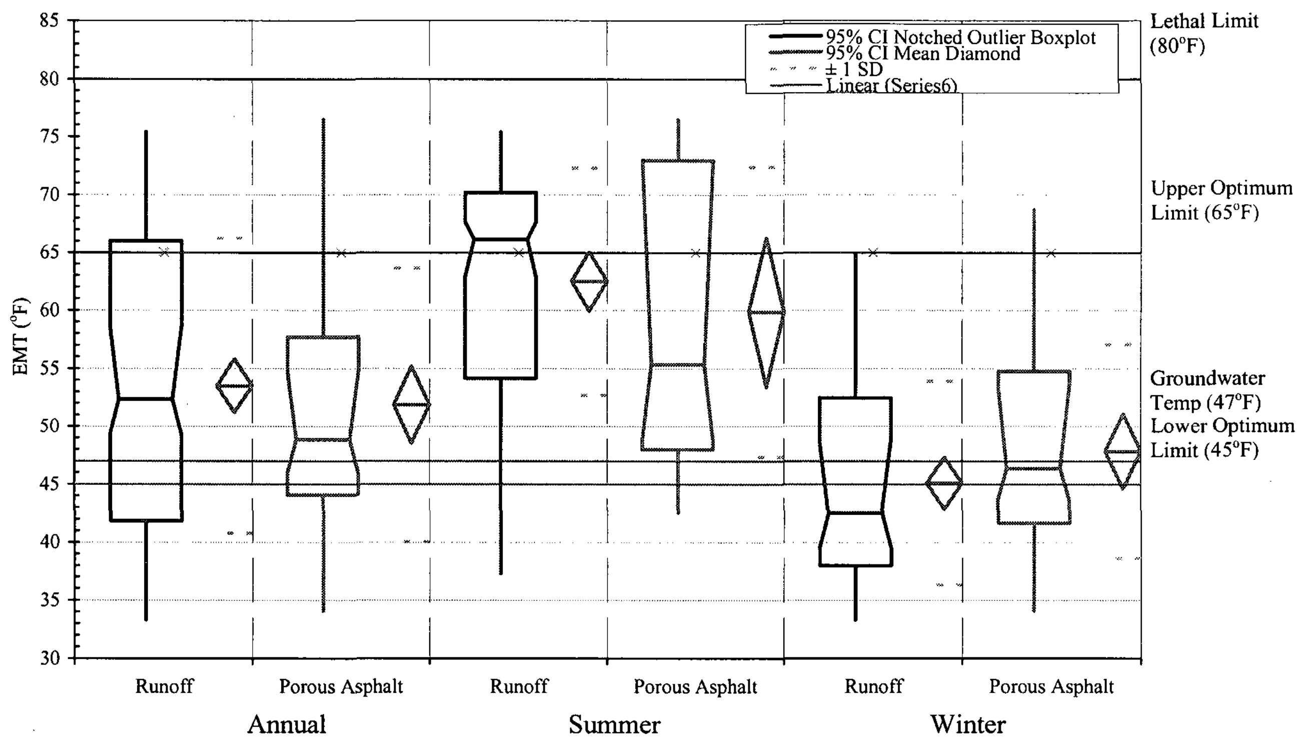
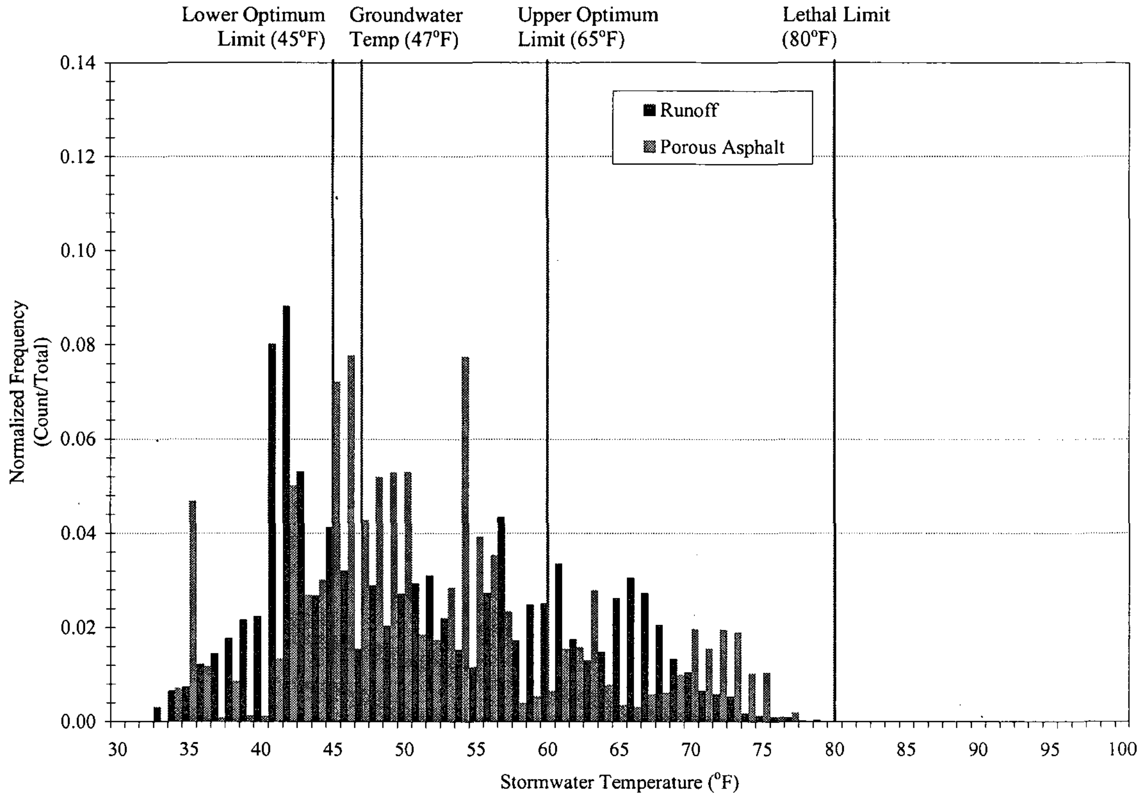


Table 22: Box and Whisker Summary

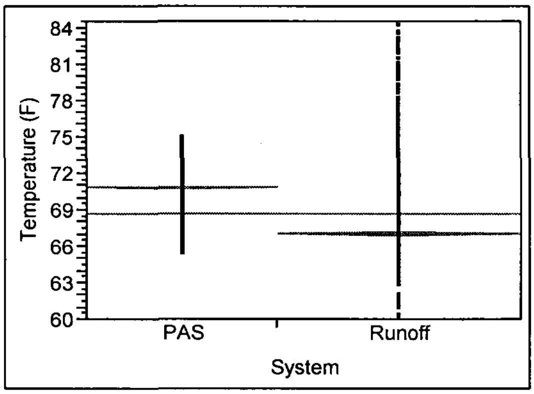
		Combined Annual		Summer		Winter	
		Runoff	Porous Asphalt	Runoff	Porous Asphalt	Runoff	Porous Asphalt
EMT (°F)	Sample Size	120	51	58	17	62	34
	Minimum	33.3	34.1	37.3	42.6	33.3	34.1
	25th Percentile	41.8	44.1	54.2	48	38	41.7
	Median	52.4	48.9	66.2	55.4	42.5	46.4
	75th Percentile	66	57.7	70.2	73	52.5	54.8
	Maximum	75.4	76.5	75.4	76.5	64.8	68.8
	Standard Deviation	12.7	11.8	9.8	12.5	8.8	9.2
	Mean	53.5	51.9	62.5	59.9	45.1	47.8
Mean July Temperatures (°F)				67.1	70.8		

Figure 39: Frequency Distribution



Statistical Analyses

Mean July Temperatures



Oneway Anova

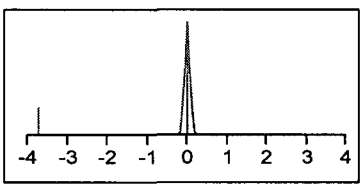
Summary of Fit

Rsquare	0.285598
Adj Rsquare	0.285502
Root Mean Square Error	2.933934
Mean of Response	68.70966
Observations (or Sum Wgts)	7485

t Test: Runoff-PAS

Assuming equal variances

Difference	-3.7418	t Ratio	-54.6945
Std Err Dif	0.0684	DF	7483
Upper CL Dif	-3.6076	Prob > |t|	0.0000*
Lower CL Dif	-3.8759	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

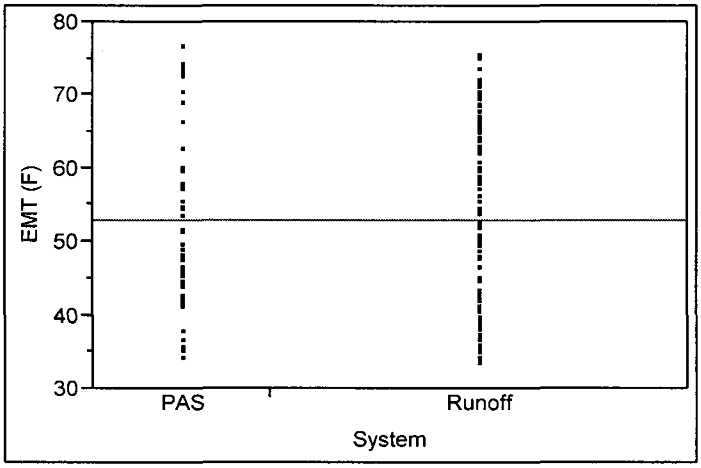
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	25750.678	25750.7	2991.493	0.0000*
Error	7483	64413.433	8.6		
C. Total	7484	90164.112			

Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
PAS	3253	70.8252	0.05144	70.724	70.926
Runoff	4232	67.0835	0.04510	66.995	67.172

Std Error uses a pooled estimate of error variance

Porous Asphalt (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
PAS	51	4200.50	82.3627	-0.625
Runoff	120	10505.5	87.5458	0.625

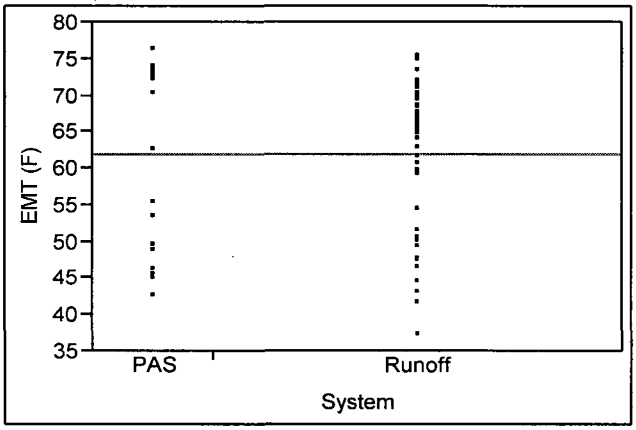
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
4200.5	-0.62465	0.5322

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.3923	1	0.5311

Porous Asphalt (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
PAS	17	628.500	36.9706	-0.215
Runoff	58	2221.50	38.3017	0.215

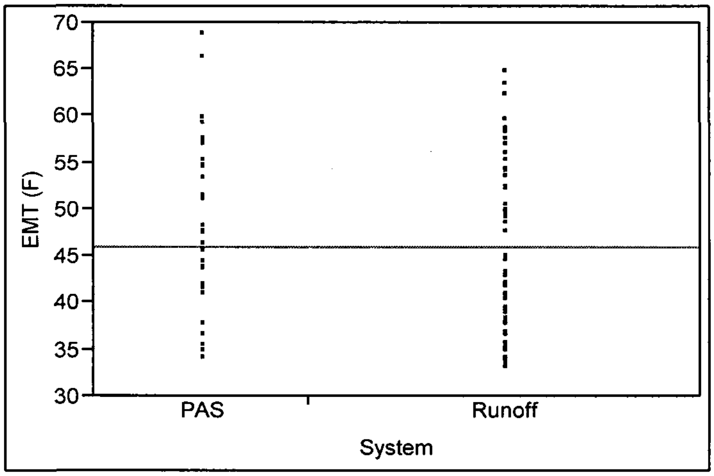
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
628.5	-0.21515	0.8297

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.0491	1	0.8247

Porous Asphalt (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
PAS	34	1836.00	54.0000	1.429
Runoff	62	2820.00	45.4839	-1.429

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1836	1.42881	0.1531

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.0525	1	0.1520

Porous Asphalt (Annual)

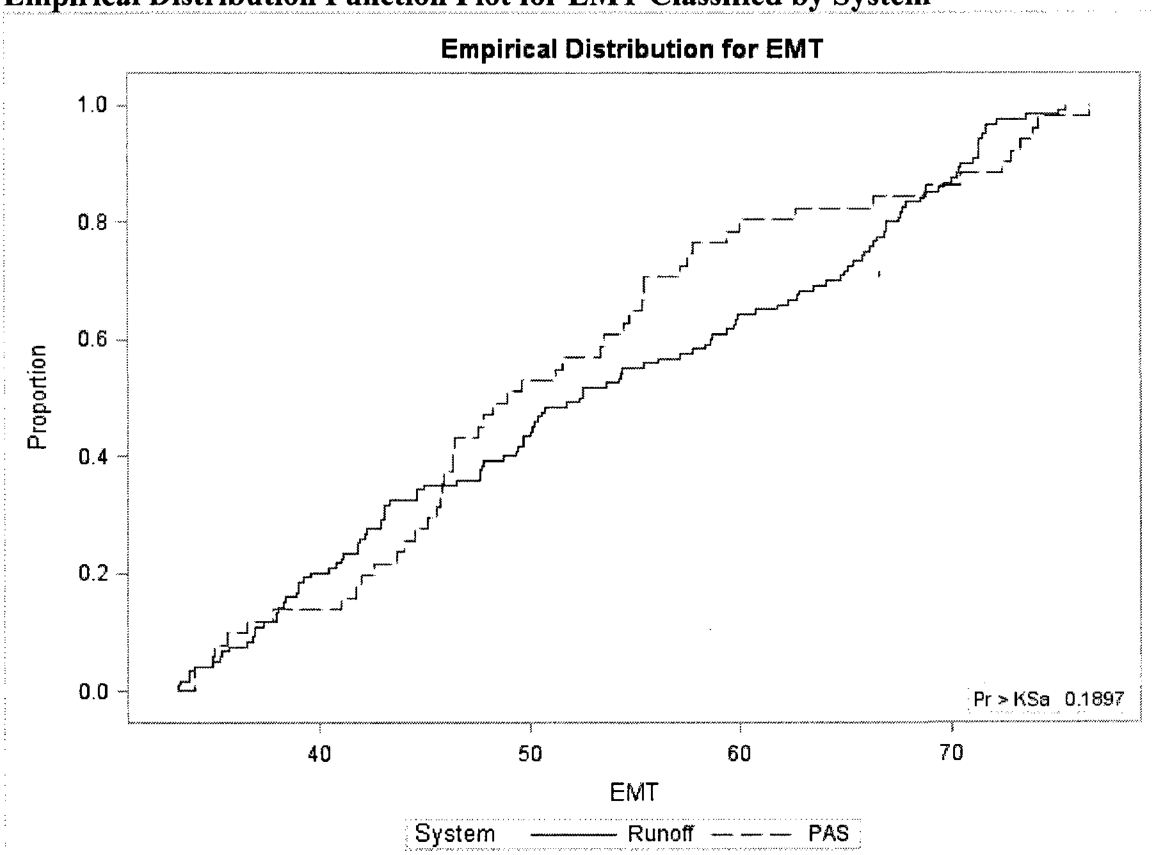
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.58333	-0.5926
PAS	51	0.76471	0.90895
Total	171	0.63743	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.082976	D	0.181373
KSa	1.085049	Pr > KSa	0.1897

Empirical Distribution Function Plot for EMT Classified by System



Porous Asphalt (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

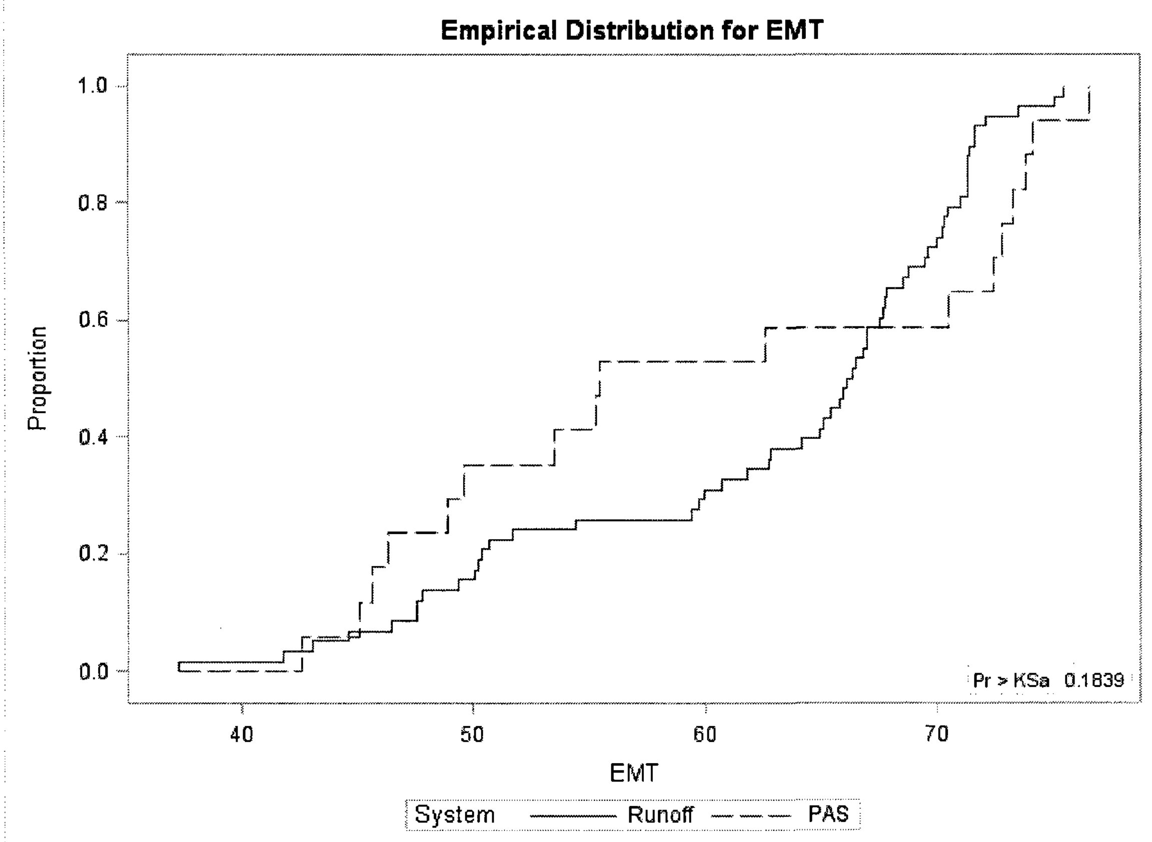
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.94828	0.51997
PAS	17	0.64706	-0.9604
Total	75	0.88	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.126112	D	0.301217
KSa	1.092163	Pr > KSa	0.1839

Empirical Distribution Function Plot for EMT Classified by System



Porous Asphalt (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

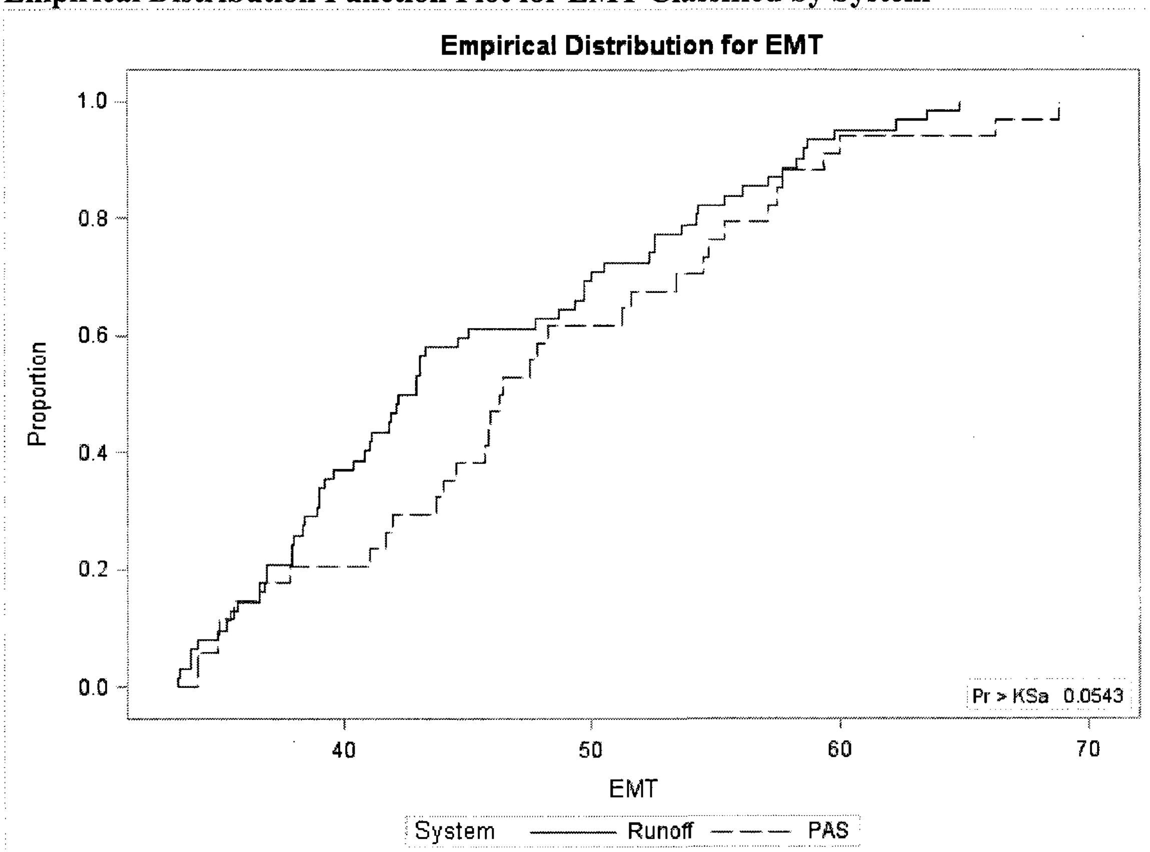
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.58065	0.79904
PAS	34	0.29412	-1.079
Total	96	0.47917	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.137035	D	0.286528
KSa	1.342660	Pr > KSa	0.0543

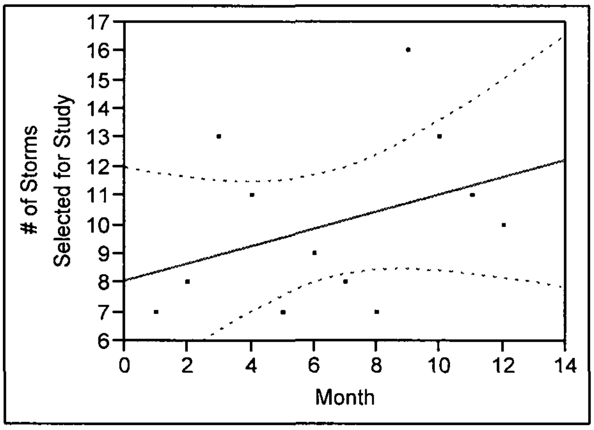
Empirical Distribution Function Plot for EMT Classified by System



APPENDIX C

STORM DISTRIBUTION STATISTICS

Bivariate Fit of # of Storms Selected for Study By Month



Linear Fit: Y = 8.1 + 0.29X

Summary of Fit	
RSquare	0.134083
RSquare Adj	0.047492
Root Mean Square Error	2.822487
Mean of Response	10
Observations (or Sum Wgts)	12

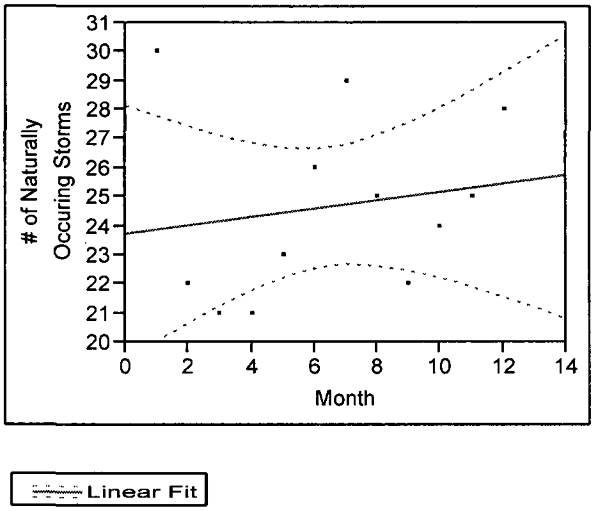
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	12.335664	12.3357	1.5485
Error	10	79.664336	7.9664	**Prob > F**
C. Total	11	92.000000		0.2417

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	8.0909091	1.737121	4.66	0.0009*
Month	0.2937063	0.236028	1.24	0.2417

Bivariate Fit of # of Naturally Occurring Storms By Month



Linear Fit: Y = 23.8 + 0.14X

Summary of Fit	
RSquare	0.026725
RSquare Adj	-0.0706
Root Mean Square Error	3.1917
Mean of Response	24.66667
Observations (or Sum Wgts)	12

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2.79720	2.7972	0.2746
Error	10	101.86946	10.1869	**Prob > F**
C. Total	11	104.66667		0.6117

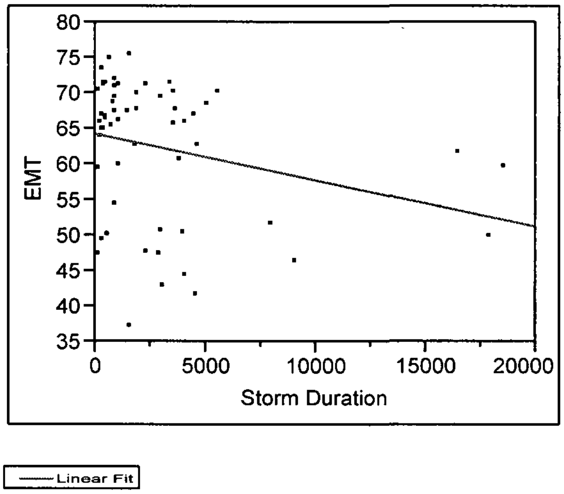
Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	23.757576	1.964355	12.09	<.0001*
Month	0.1398601	0.266903	0.52	0.6117

APPENDIX D

STORM CHARACTERISTIC STATISTICS

Bivariate Fit of EMT By Storm Duration Season=Summer



Linear Fit: EMT = 64.366951 - 0.0006599*Storm Duration

Summary of Fit

RSquare	0.072446
RSquare Adj	0.055882
Root Mean Square Error	9.523422
Mean of Response	62.5069
Observations (or Sum Wgts)	58

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	51	4415.4112	86.577	0.6524
Pure Error	5	663.5400	132.708	**Prob > F**
Total Error	56	5078.9512		0.8038
				Max RSq
				0.8788

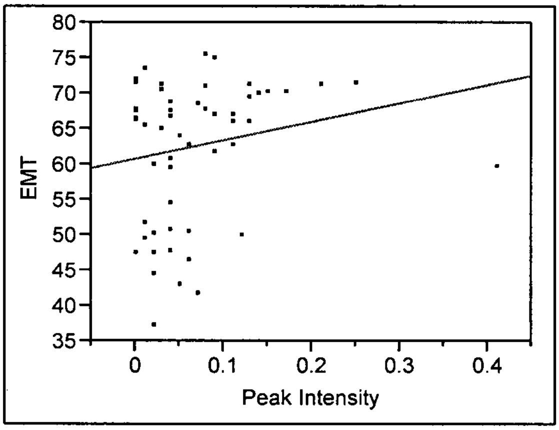
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	396.6860	396.686	4.3738
Error	56	5078.9512	90.696	**Prob > F**
C. Total	57	5475.6372		0.0410*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	64.366951	1.534517	41.95	<.0001*
Storm Duration	-0.00066	0.000316	-2.09	0.0410*

Bivariate Fit of EMT By Peak Intensity Season=Summer



Linear Fit: EMT = 60.741892 + 26.114865*Peak Intensity

Summary of Fit

RSquare	0.037248
RSquare Adj	0.020056
Root Mean Square Error	9.702431
Mean of Response	62.5069
Observations (or Sum Wgts)	58

Lack Of Fit

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Lack Of Fit	17	2799.9887	164.705	2.5988
Pure Error	39	2471.6923	63.377	**Prob > F**
Total Error	56	5271.6810		0.0069*
				Max RSq
				0.5486

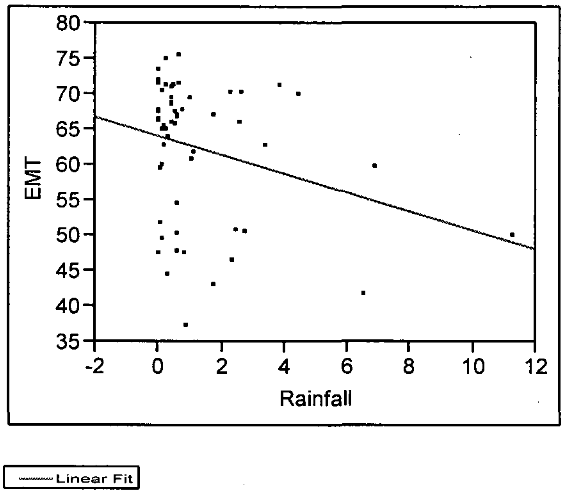
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	203.9562	203.956	2.1666
Error	56	5271.6810	94.137	**Prob > F**
C. Total	57	5475.6372		0.1466

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	60.741892	1.749546	34.72	<.0001*
Peak Intensity	26.114865	17.74189	1.47	0.1466

Bivariate Fit of EMT By Rainfall Season=Summer



Linear Fit: EMT = 64.110373 - 1.3406608*Rainfall

Summary of Fit

RSquare	0.07575
RSquare Adj	0.059246
Root Mean Square Error	9.506441
Mean of Response	62.5069
Observations (or Sum Wgts)	58

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	40	3821.5711	95.5393	1.2335
Pure Error	16	1239.2839	77.4552	**Prob > F**
Total Error	56	5060.8550		0.3340
				Max RSq
				0.7737

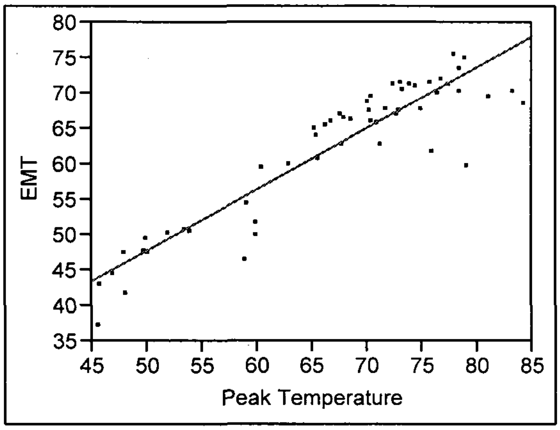
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	414.7822	414.782	4.5897
Error	56	5060.8550	90.372	**Prob > F**
C. Total	57	5475.6372		0.0365*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	64.110373	1.455453	44.05	<.0001*
Rainfall	-1.340661	0.625787	-2.14	0.0365*

Bivariate Fit of EMT By Peak Temperature Season=Summer



Linear Fit: EMT = 4.807992 + 0.8613772*Peak Temperature

Summary of Fit

RSquare	0.837875
RSquare Adj	0.83498
Root Mean Square Error	3.981517
Mean of Response	62.5069
Observations (or Sum Wgts)	58

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	50	880.28895	17.6058	14.1792
Pure Error	6	7.45000	1.2417	**Prob > F**
Total Error	56	887.73895		0.0015*
				Max RSq
				0.9986

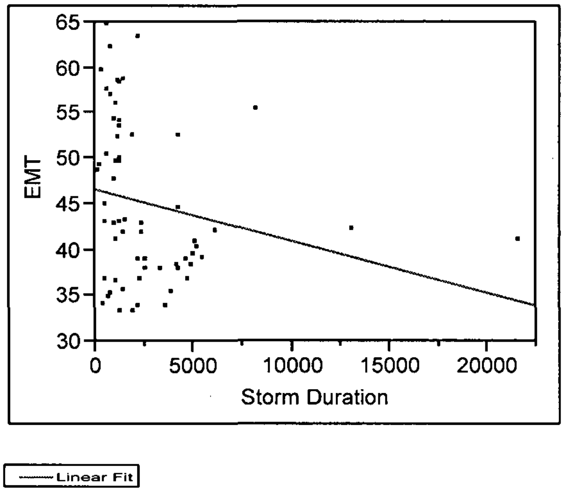
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4587.8983	4587.90	289.4120
Error	56	887.7389	15.85	**Prob > F**
C. Total	57	5475.6372		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.807992	3.431693	1.40	0.1667
Peak Temperature	0.8613772	0.050633	17.01	<.0001*

Bivariate Fit of EMT By Storm Duration Season=Winter



Linear Fit: EMT = 46.589619 - 0.0005602*Storm Duration

Summary of Fit

RSquare	0.04471
RSquare Adj	0.028788
Root Mean Square Error	8.660335
Mean of Response	45.10645
Observations (or Sum Wgts)	62

Lack Of Fit

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Lack Of Fit	57	4372.8938	76.7174	1.8095
Pure Error	3	127.1900	42.3967	**Prob > F**
Total Error	60	4500.0838		0.3515
				Max RSq
				0.9730

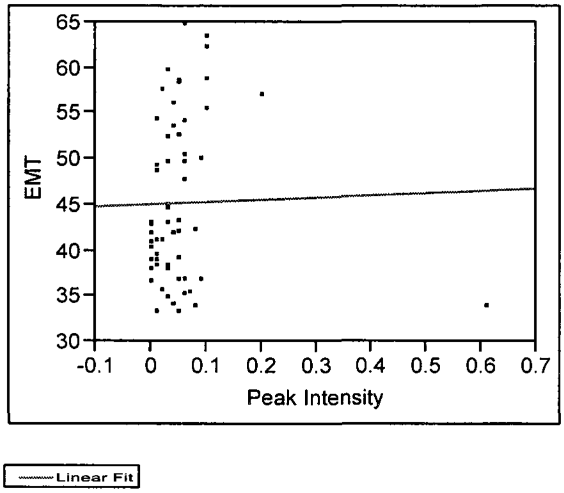
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	210.6136	210.614	2.8081
Error	60	4500.0838	75.001	**Prob > F**
C. Total	61	4710.6974		0.0990

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	46.589619	1.411759	33.00	<.0001*
Storm Duration	-0.00056	0.000334	-1.68	0.0990

Bivariate Fit of EMT By Peak Intensity Season=Winter



Linear Fit: EMT = 44.979622 + 2.5365977*Peak Intensity

Summary of Fit

RSquare	0.000541
RSquare Adj	-0.01612
Root Mean Square Error	8.858281
Mean of Response	45.10645
Observations (or Sum Wgts)	62

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	11	1700.2844	154.571	2.5181
Pure Error	49	3007.8637	61.385	**Prob > F**
Total Error	60	4708.1481		0.0134*
				Max RSq
				0.3615

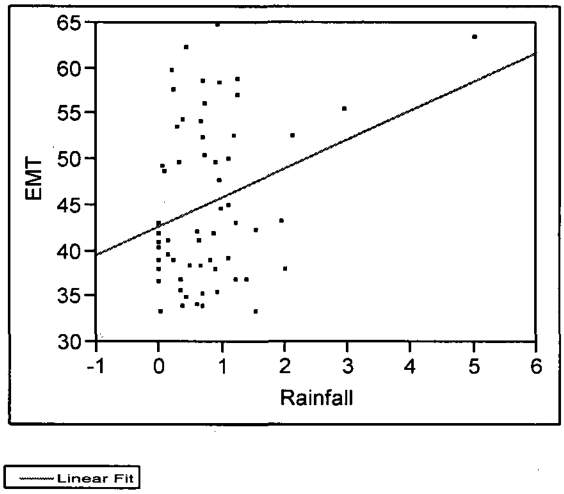
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.5493	2.5493	0.0325
Error	60	4708.1481	78.4691	**Prob > F**
C. Total	61	4710.6974		0.8576

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	44.979622	1.326939	33.90	<.0001*
Peak Intensity	2.5365977	14.07318	0.18	0.8576

Bivariate Fit of EMT By Rainfall Season=Winter



Linear Fit: EMT = 42.656314 + 3.1753451*Rainfall

Summary of Fit

RSquare	0.087218
RSquare Adj	0.072005
Root Mean Square Error	8.465458
Mean of Response	45.10645
Observations (or Sum Wgts)	62

Lack Of Fit

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Lack Of Fit	41	3280.8267	80.0202	1.4920
Pure Error	19	1019.0117	53.6322	**Prob > F**
Total Error	60	4299.8384		0.1747
				Max RSq
				0.7837

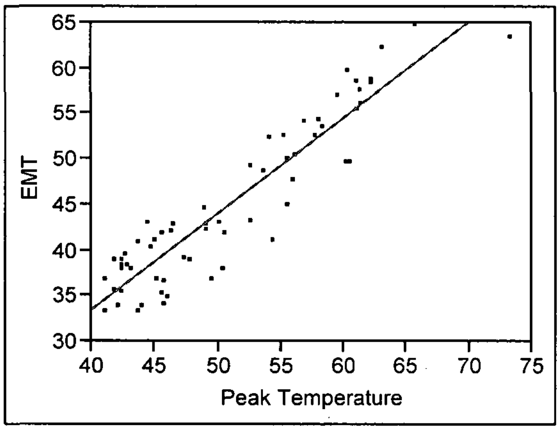
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	410.8590	410.859	5.7331
Error	60	4299.8384	71.664	**Prob > F**
C. Total	61	4710.6974		0.0198*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	42.656314	1.484241	28.74	<.0001*
Rainfall	3.1753451	1.326157	2.39	0.0198*

Bivariate Fit of EMT By Peak Temperature Season=Winter



Linear Fit: EMT = -8.72192 + 1.0541914*Peak Temperature

Summary of Fit

RSquare	0.860215
RSquare Adj	0.857885
Root Mean Square Error	3.312817
Mean of Response	45.10645
Observations (or Sum Wgts)	62

Lack Of Fit

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Lack Of Fit	47	550.14875	11.7053	1.4046
Pure Error	13	108.33667	8.3336	**Prob > F**
Total Error	60	658.48542		0.2578
				Max RSq
				0.9770

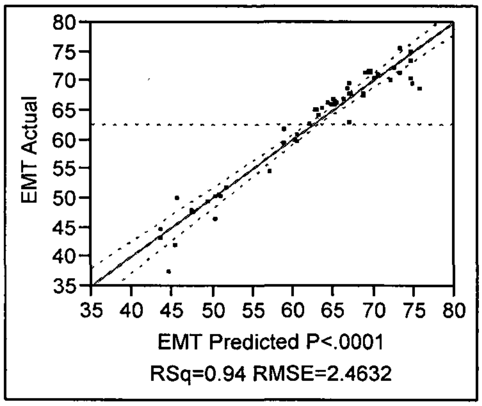
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	4052.2120	4052.21	369.2302
Error	60	658.4854	10.97	**Prob > F**
C. Total	61	4710.6974		<.0001*

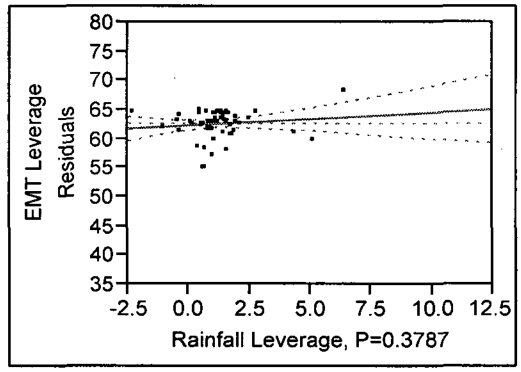
Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-8.72192	2.832738	-3.08	0.0031*
Peak Temperature	1.0541914	0.054862	19.22	<.0001*

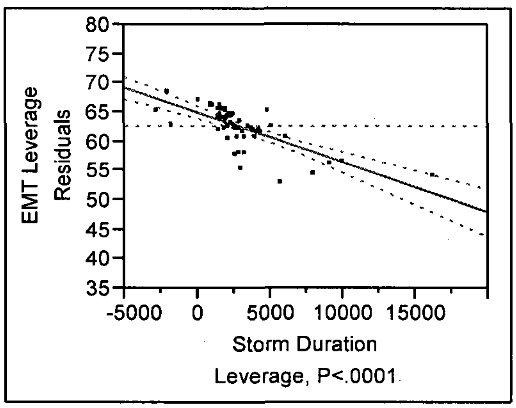
Response EMT Season=Summer
Whole Model
Actual by Predicted Plot



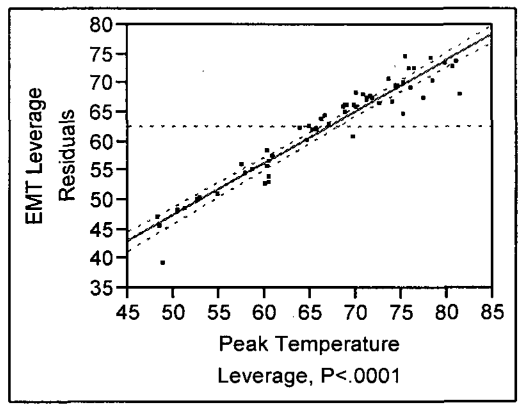
Rainfall
Leverage Plot



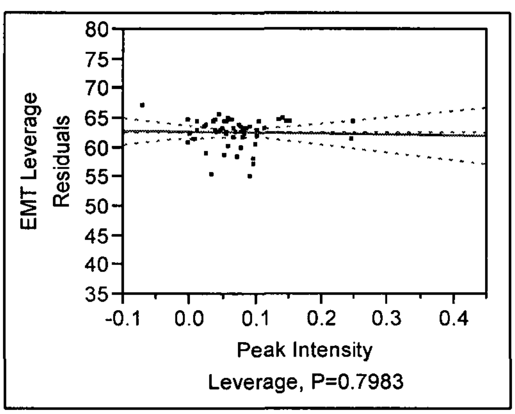
Storm Duration
Leverage Plot



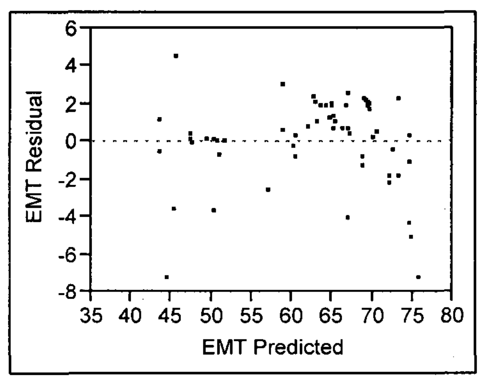
Peak Temperature
Leverage Plot



Peak Intensity
Leverage Plot



Residual by Predicted Plot



Summary of Fit	
RSquare	0.941274
RSquare Adj	0.936842
Root Mean Square Error	2.463173
Mean of Response	62.5069
Observations (or Sum Wgts)	58

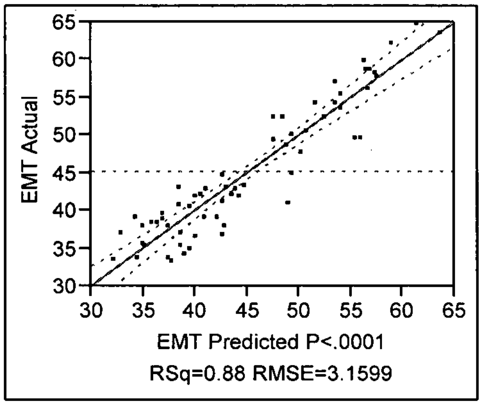
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	5154.0746	1288.52	212.3738
Error	53	321.5626	6.07	**Prob > F**
C. Total	57	5475.6372		<.0001*

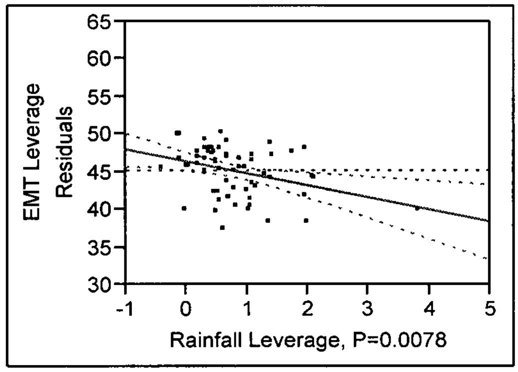
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.3406008	2.342595	2.28	0.0267*
Storm Duration	-0.000853	0.000116	-7.37	<.0001*
Peak Intensity	-1.592073	6.199262	-0.26	0.7983
Rainfall	0.2269009	0.255615	0.89	0.3787
Peak Temperature	0.8868871	0.036163	24.52	<.0001*

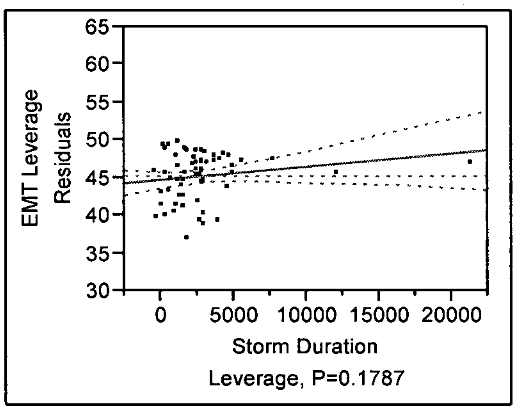
Response EMT Season=Winter
Whole Model
Actual by Predicted Plot



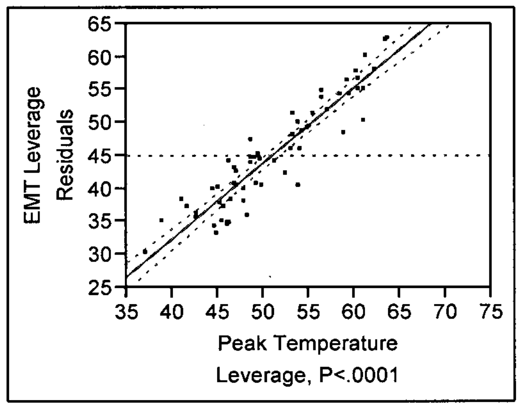
Rainfall
Leverage Plot



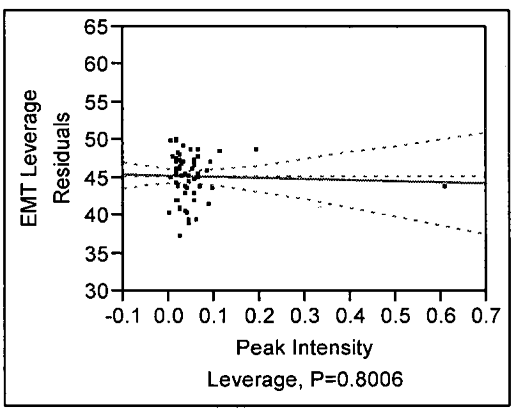
Storm Duration
Leverage Plot



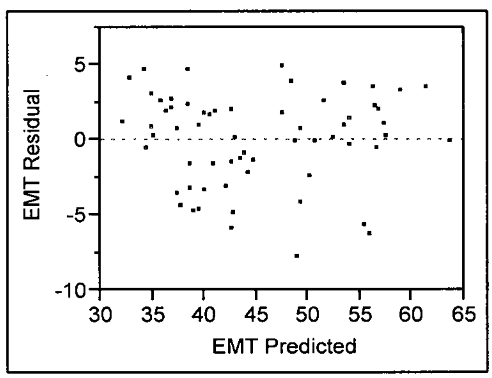
Peak Temperature
Leverage Plot



Peak Intensity
Leverage Plot



Residual by Predicted Plot



Summary of Fit	
RSquare	0.879183
RSquare Adj	0.870704
Root Mean Square Error	3.159874
Mean of Response	45.10645
Observations (or Sum Wgts)	62

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	4141.5635	1035.39	103.6966
Error	57	569.1339	9.98	**Prob > F**
C. Total	61	4710.6974		<.0001*

Parameter Estimates

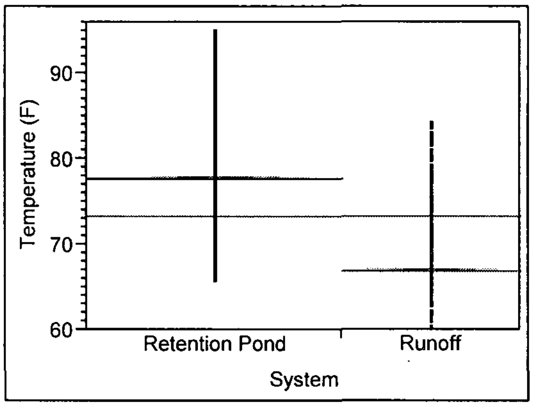
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-12.72467	3.134942	-4.06	0.0002*
Storm Duration	0.0001767	0.00013	1.36	0.1787
Peak Intensity	-1.310598	5.16502	-0.25	0.8006
Rainfall	-1.597723	0.579459	-2.76	0.0078*
Peak Temperature	1.148846	0.061741	18.61	<.0001*

APPENDIX E

MEAN JULY STATISTICS

Retention Pond

Mean July Temperatures



Oneway Anova

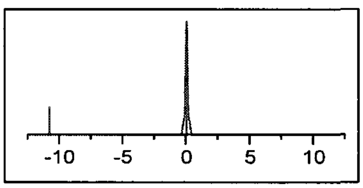
Summary of Fit

Rsquare	0.50831
Adj Rsquare	0.508262
Root Mean Square Error	5.229293
Mean of Response	73.43639
Observations (or Sum Wgts)	10275

t Test: Runoff-Retention Pond

Assuming equal variances

Difference	-10.802	t Ratio	-103.054
Std Err Dif	0.105	DF	10273
Upper CL Dif	-10.596	Prob > |t|	0.0000*
Lower CL Dif	-11.007	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	290415.50	290416	10620.23	0.0000*
Error	10273	280920.42	27		
C. Total	10274	571335.92			

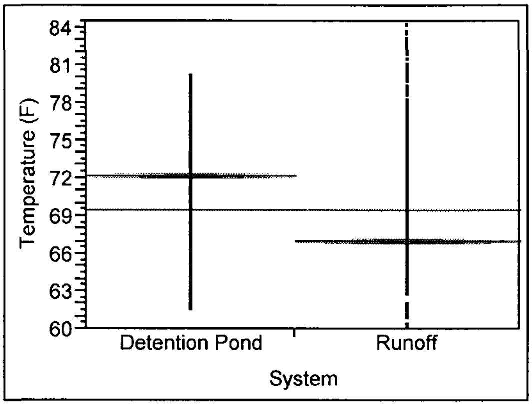
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Retention Pond	6043	77.8854	0.06727	77.754	78.017
Runoff	4232	67.0835	0.08038	66.926	67.241

Std Error uses a pooled estimate of error variance

Detention Pond

Mean July Temperatures



Oneway Anova

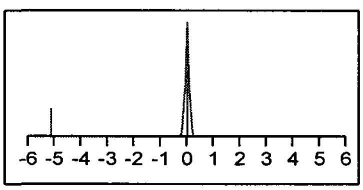
Summary of Fit

Rsquare	0.36025
Adj Rsquare	0.360171
Root Mean Square Error	3.42455
Mean of Response	69.54284
Observations (or Sum Wgts)	8109

t Test: Runoff-Detention Pond

Assuming equal variances

Difference	-5.1439	t Ratio	-67.5658
Std Err Dif	0.0761	DF	8107
Upper CL Dif	-4.9947	Prob > |t|	0.0000*
Lower CL Dif	-5.2931	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	53537.83	53537.8	4565.137	0.0000*
Error	8107	95075.17	11.7		
C. Total	8108	148613.00			

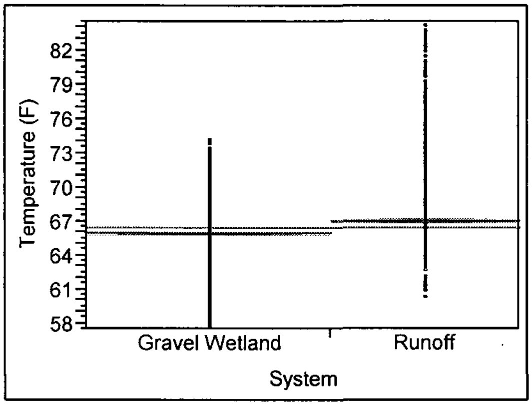
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Detention Pond	3877	72.2274	0.05500	72.120	72.335
Runoff	4232	67.0835	0.05264	66.980	67.187

Std Error uses a pooled estimate of error variance

Gravel Wetland

Mean July Temperatures



Oneway Anova

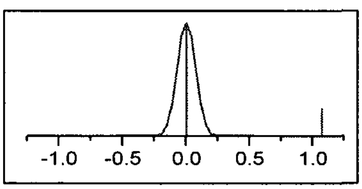
Summary of Fit

Rsquare	0.02056
Adj Rsquare	0.020459
Root Mean Square Error	3.641098
Mean of Response	66.48324
Observations (or Sum Wgts)	9712

t Test: Runoff-Gravel Wetland

Assuming equal variances

Difference	1.06379	t Ratio	14.27689
Std Err Dif	0.07451	DF	9710
Upper CL Dif	1.20985	Prob > |t|	<.0001*
Lower CL Dif	0.91774	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	2702.29	2702.29	203.8296	<.0001*
Error	9710	128731.26	13.26		
C. Total	9711	131433.55			

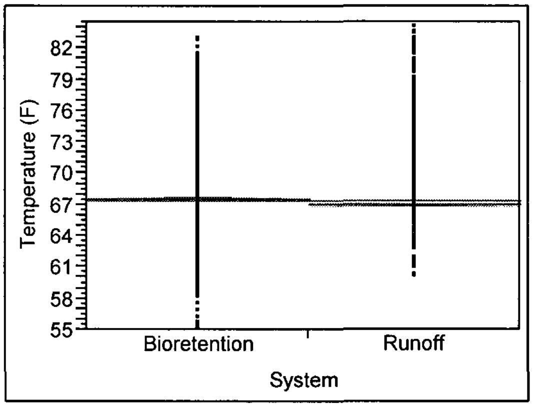
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Gravel Wetland	5480	66.0197	0.04919	65.923	66.116
Runoff	4232	67.0835	0.05597	66.974	67.193

Std Error uses a pooled estimate of error variance

Bioretention

Mean July Temperatures



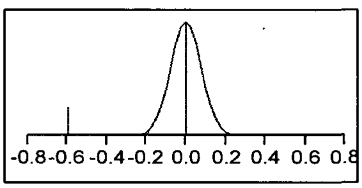
Oneway Anova

Summary of Fit	
Rsquare	0.006991
Adj Rsquare	0.006877
Root Mean Square Error	3.568833
Mean of Response	67.39082
Observations (or Sum Wgts)	8691

t Test: Runoff-Bioretention

Assuming equal variances

Difference	-0.59902	t Ratio	-7.82123
Std Err Dif	0.07659	DF	8689
Upper CL Dif	-0.44889	Prob > |t|	<.0001*
Lower CL Dif	-0.74916	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	779.12	779.116	61.1716	<.0001*
Error	8689	110668.05	12.737		
C. Total	8690	111447.17			

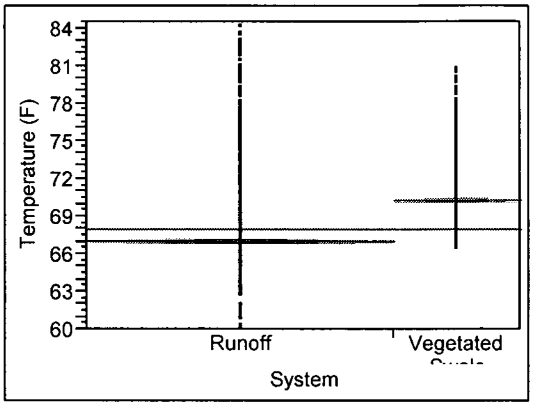
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Bioretention	4459	67.6825	0.05345	67.578	67.787
Runoff	4232	67.0835	0.05486	66.976	67.191

Std Error uses a pooled estimate of error variance

Vegetated Swale

Mean July Temperatures



Oneway Anova

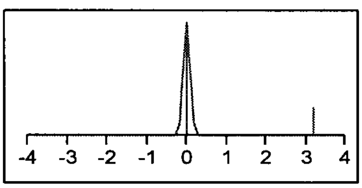
Summary of Fit

Rsquare	0.174919
Adj Rsquare	0.174782
Root Mean Square Error	3.181354
Mean of Response	68.02823
Observations (or Sum Wgts)	5993

t Test: Vegetated Swale-Runoff

Assuming equal variances

Difference	3.21515	t Ratio	35.63857
Std Err Dif	0.09022	DF	5991
Upper CL Dif	3.39201	Prob > |t|	<.0001*
Lower CL Dif	3.03830	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	12854.771	12854.8	1270.107	<.0001*
Error	5991	60634.972	10.1		
C. Total	5992	73489.743			

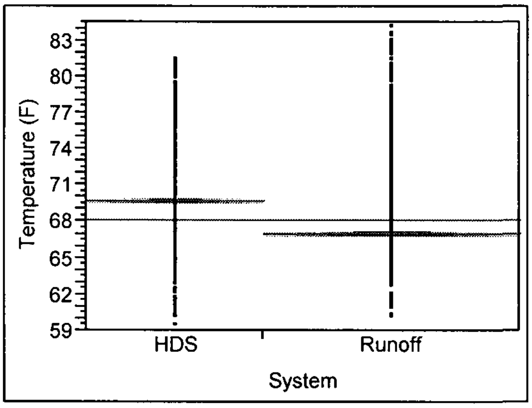
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Runoff	4232	67.0835	0.04890	66.988	67.179
Vegetated Swale	1761	70.2986	0.07581	70.150	70.447

Std Error uses a pooled estimate of error variance

<u>Hydrodynamic Separators</u>

Mean July Temperatures



Oneway Anova

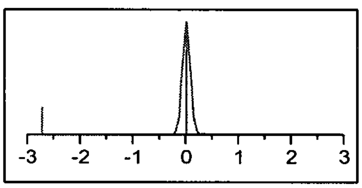
Summary of Fit

Rsquare	0.15513
Adj Rsquare	0.155012
Root Mean Square Error	3.123216
Mean of Response	68.19404
Observations (or Sum Wgts)	7147

t Test: Runoff-HDS

Assuming equal variances

Difference	-2.7229	t Ratio	-36.2205
Std Err Dif	0.0752	DF	7145
Upper CL Dif	-2.5755	Prob > |t|	0.0000*
Lower CL Dif	-2.8702	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
System	1	12797.118	12797.1	1311.922	<.0001*
Error	7145	69695.748	9.8		
C. Total	7146	82492.866			

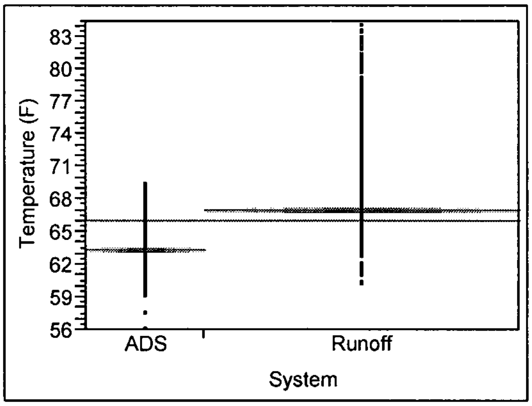
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
HDS	2915	69.8063	0.05785	69.693	69.920
Runoff	4232	67.0835	0.04801	66.989	67.178

Std Error uses a pooled estimate of error variance

<u>ADS Infiltration System</u>

Mean July Temperatures

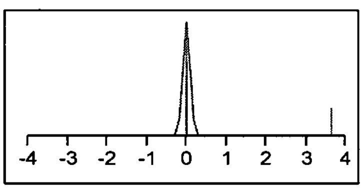


Oneway Anova	
Summary of Fit	
Rsquare	0.196402
Adj Rsquare	0.196264
Root Mean Square Error	3.271096
Mean of Response	66.09805
Observations (or Sum Wgts)	5804

t Test: Runoff-ADS

Assuming equal variances

Difference	3.63832	t Ratio	37.65674
Std Err Dif	0.09662	DF	5802
Upper CL Dif	3.82772	Prob > |t|	<.0001*
Lower CL Dif	3.44891	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	15173.019	15173.0	1418.030	<.0001*
Error	5802	62081.809	10.7		
C. Total	5803	77254.828			

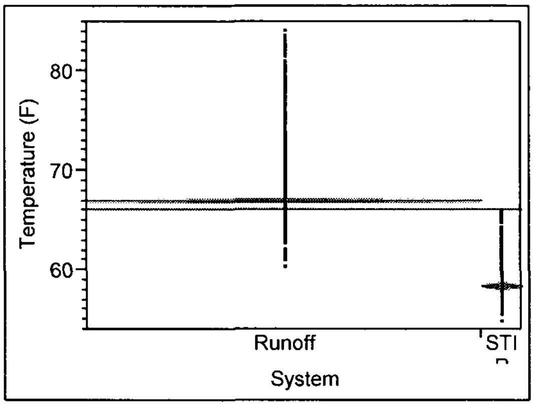
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
ADS	1572	63.4452	0.08250	63.283	63.607
Runoff	4232	67.0835	0.05028	66.985	67.182

Std Error uses a pooled estimate of error variance

StormTech Isolator Row

Mean July Temperatures



Oneway Anova

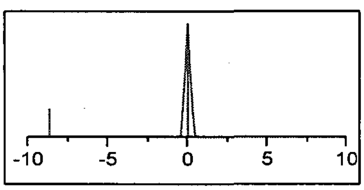
Summary of Fit

Rsquare	0.342459
Adj Rsquare	0.342317
Root Mean Square Error	3.436255
Mean of Response	66.29963
Observations (or Sum Wgts)	4655

t Test: STIR-Runoff

Assuming equal variances

Difference	-8.6260	t Ratio	-49.2276
Std Err Dif	0.1752	DF	4653
Upper CL Dif	-8.2825	Prob > |t|	0.0000*
Lower CL Dif	-8.9696	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
System	1	28614.680	28614.7	2423.361	0.0000*
Error	4653	54941.930	11.8		
C. Total	4654	83556.609			

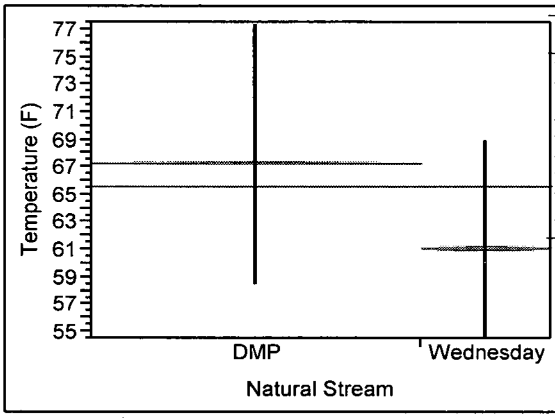
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Runoff	4232	67.0835	0.05282	66.980	67.187
STIR	423	58.4574	0.16708	58.130	58.785

Std Error uses a pooled estimate of error variance

College Brook (d/s) vs. Wednesday Hill Brook

Mean July Temperature



Oneway Anova

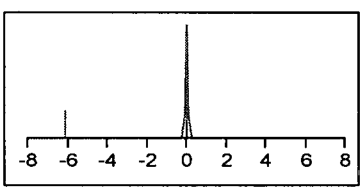
Summary of Fit

Rsquare	0.419558
Adj Rsquare	0.419503
Root Mean Square Error	3.279109
Mean of Response	65.56336
Observations (or Sum Wgts)	10412

t Test: Wednesday-DMP

Assuming equal variances

Difference	-6.1699	t Ratio	-86.7446
Std Err Dif	0.0711	DF	10410
Upper CL Dif	-6.0305	Prob > |t|	0.0000*
Lower CL Dif	-6.3093	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	80908.90	80908.9	7524.622	0.0000*
Error	10410	111934.09	10.8		
C. Total	10411	192842.99			

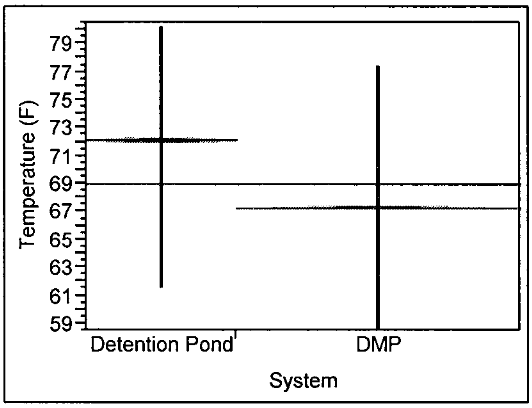
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
DMP	7436	67.3269	0.03803	67.252	67.401
Wednesday	2976	61.1570	0.06011	61.039	61.275

Std Error uses a pooled estimate of error variance

Detention Pond vs. College Brook (d/s)

Mean July Temperature



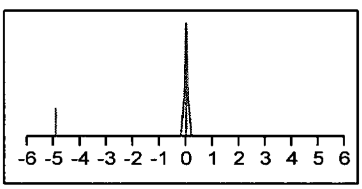
Oneway Anova

Summary of Fit	
Rsquare	0.325457
Adj Rsquare	0.325398
Root Mean Square Error	3.348716
Mean of Response	69.00629
Observations (or Sum Wgts)	11313

t Test: DMP-Detention Pond

Assuming equal variances

Difference	-4.9005	t Ratio	-73.8742
Std Err Dif	0.0663	DF	11311
Upper CL Dif	-4.7705	Prob > |t|	0.0000*
Lower CL Dif	-5.0306	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	61198.71	61198.7	5457.398	0.0000*
Error	11311	126840.40	11.2		
C. Total	11312	188039.11			

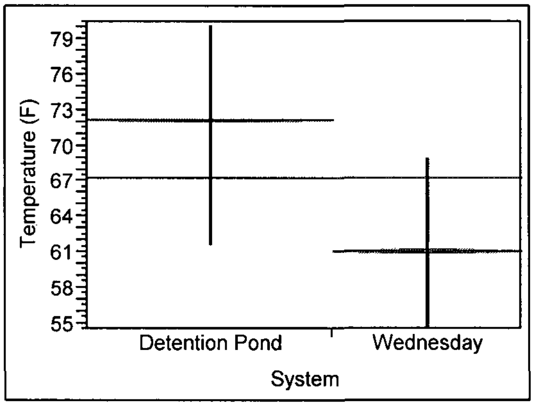
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
Detention Pond	3877	72.2274	0.05378	72.122	72.333
DMP	7436	67.3269	0.03883	67.251	67.403

Std Error uses a pooled estimate of error variance

Detention Pond vs. Wednesday Hill Brook

Mean July Temperature



Oneway Anova

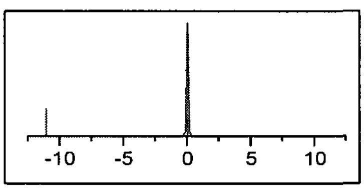
Summary of Fit

Rsquare	0.743364
Adj Rsquare	0.743326
Root Mean Square Error	3.224556
Mean of Response	67.41992
Observations (or Sum Wgts)	6853

t Test: Wednesday-Detention Pond

Assuming equal variances

Difference	-11.070	t Ratio	-140.87
Std Err Dif	0.079	DF	6851
Upper CL Dif	-10.916	Prob > |t|	0.0000*
Lower CL Dif	-11.224	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	206337.18	206337	19844.38	0.0000*
Error	6851	71235.07	10		
C. Total	6852	277572.25			

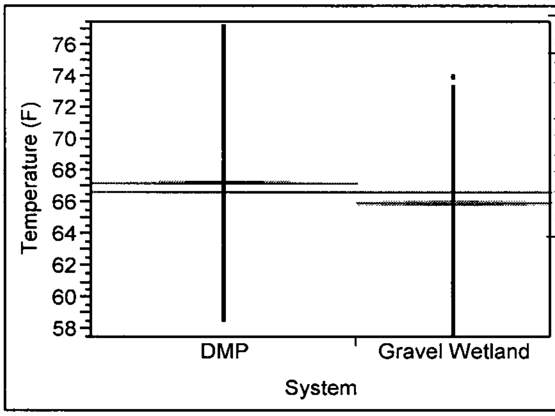
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Detention Pond	3877	72.2274	0.05179	72.126	72.329
Wednesday	2976	61.1570	0.05911	61.041	61.273

Std Error uses a pooled estimate of error variance

Gravel Wetland vs. College Brook (d/s)

Mean July Temperature



Oneway Anova

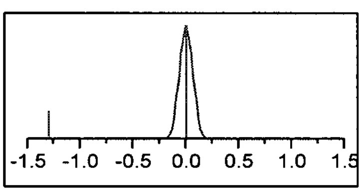
Summary of Fit

Rsquare	0.032497
Adj Rsquare	0.032423
Root Mean Square Error	3.525351
Mean of Response	66.77226
Observations (or Sum Wgts)	12916

t Test: Gravel Wetland-DMP

Assuming equal variances

Difference	-1.3072	t Ratio	-20.8271
Std Err Dif	0.0628	DF	12914
Upper CL Dif	-1.1842	Prob > |t|	0.0000*
Lower CL Dif	-1.4302	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	5390.91	5390.91	433.7681	<.0001*
Error	12914	160496.50	12.43		
C. Total	12915	165887.41			

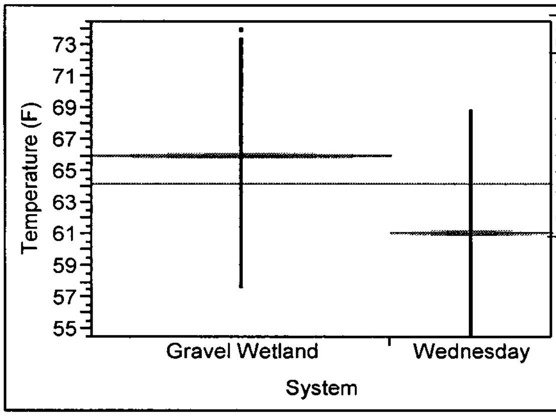
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
DMP	7436	67.3269	0.04088	67.247	67.407
Gravel Wetland	5480	66.0197	0.04762	65.926	66.113

Std Error uses a pooled estimate of error variance

Gravel Wetland vs. Wednesday Hill Brook

Mean July Temperature



Oneway Anova

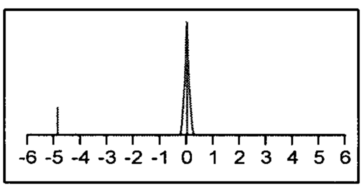
Summary of Fit

Rsquare	0.30303
Adj Rsquare	0.302947
Root Mean Square Error	3.522397
Mean of Response	64.3083
Observations (or Sum Wgts)	8456

t Test: Wednesday-Gravel Wetland

Assuming equal variances

Difference	-4.8627	t Ratio	-60.6271
Std Err Dif	0.0802	DF	8454
Upper CL Dif	-4.7055	Prob > |t|	0.0000*
Lower CL Dif	-5.0200	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	45604.70	45604.7	3675.640	0.0000*
Error	8454	104891.16	12.4		
C. Total	8455	150495.86			

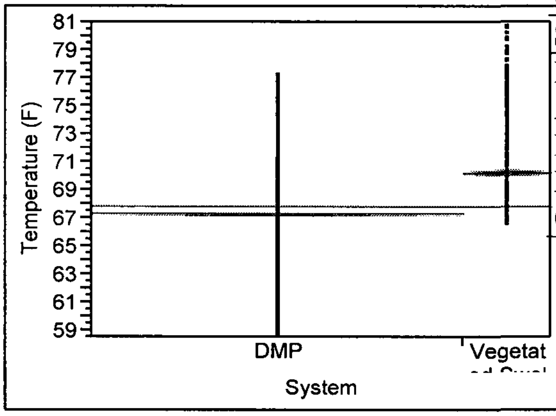
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Gravel Wetland	5480	66.0197	0.04758	65.926	66.113
Wednesday	2976	61.1570	0.06457	61.030	61.284

Std Error uses a pooled estimate of error variance

Vegetated Swale vs. College Brook (d/s)

Mean July Temperature



Oneway Anova

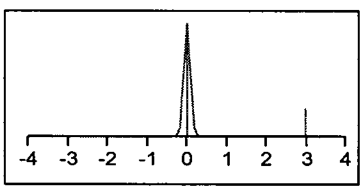
Summary of Fit

Rsquare	0.119784
Adj Rsquare	0.119688
Root Mean Square Error	3.17001
Mean of Response	67.89589
Observations (or Sum Wgts)	9197

t Test: Vegetated Swale-DMP

Assuming equal variances

Difference	2.97177	t Ratio	35.3737
Std Err Dif	0.08401	DF	9195
Upper CL Dif	3.13645	Prob > |t|	<.0001*
Lower CL Dif	2.80709	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	12574.26	12574.3	1251.299	<.0001*
Error	9195	92400.21	10.0		
C. Total	9196	104974.46			

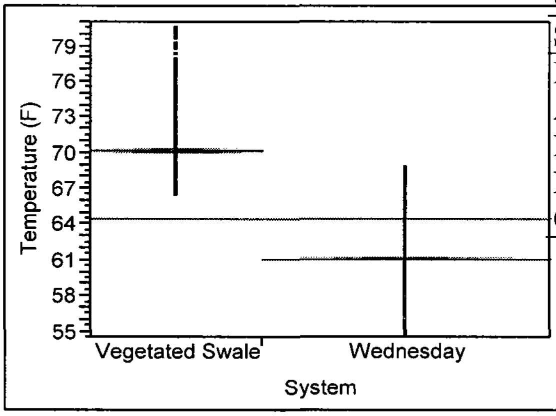
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
DMP	7436	67.3269	0.03676	67.255	67.399
Vegetated Swale	1761	70.2986	0.07554	70.151	70.447

Std Error uses a pooled estimate of error variance

Vegetated Swale vs. Wednesday Hill Brook

Mean July Temperature



Oneway Anova

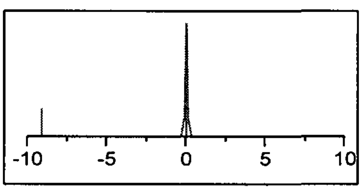
Summary of Fit

Rsquare	0.715325
Adj Rsquare	0.715265
Root Mean Square Error	2.787621
Mean of Response	64.55541
Observations (or Sum Wgts)	4737

t Test: Wednesday-Vegetated Swale

Assuming equal variances

Difference	-9.1417	t Ratio	-109.078
Std Err Dif	0.0838	DF	4735
Upper CL Dif	-8.9774	Prob > |t|	0.0000*
Lower CL Dif	-9.3060	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Label	1	92457.27	92457.3	11897.99	0.0000*
Error	4735	36794.87	7.8		
C. Total	4736	129252.14			

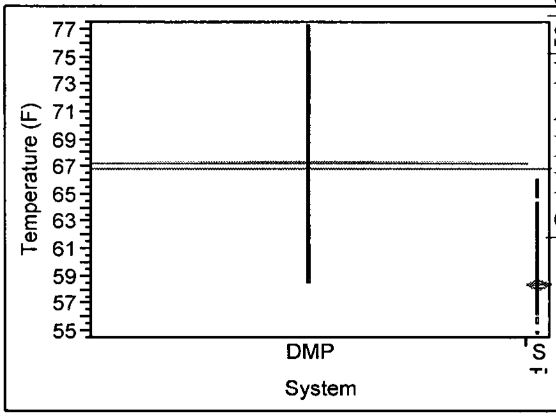
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Vegetated Swale	1761	70.2986	0.06643	70.168	70.429
Wednesday	2976	61.1570	0.05110	61.057	61.257

Std Error uses a pooled estimate of error variance

StormTech Isolator Row vs. College Brook (d/s)

Mean July Temperature



Oneway Anova

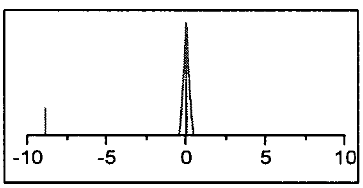
Summary of Fit

Rsquare	0.266388
Adj Rsquare	0.266295
Root Mean Square Error	3.321996
Mean of Response	66.84948
Observations (or Sum Wgts)	7859

t Test: STIR-DMP

Assuming equal variances

Difference	-8.8694	t Ratio	-53.4137
Std Err Dif	0.1661	DF	7857
Upper CL Dif	-8.5439	Prob > |t|	0.0000*
Lower CL Dif	-9.1949	Prob > t	1.0000
Confidence	0.95	Prob < t	0.0000*



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	31484.96	31485.0	2853.021	0.0000*
Error	7857	86707.17	11.0		
C. Total	7858	118192.13			

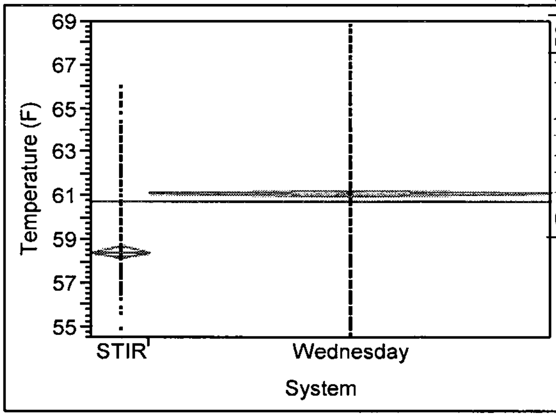
Means for Oneway Anova

Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
DMP	7436	67.3269	0.03852	67.251	67.402
STIR	423	58.4574	0.16152	58.141	58.774

Std Error uses a pooled estimate of error variance

StormTech Isolator Row vs. Wednesday Hill Brook

Mean July Temperature



Oneway Anova

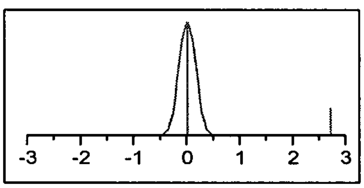
Summary of Fit

Rsquare	0.079848
Adj Rsquare	0.079577
Root Mean Square Error	3.025835
Mean of Response	60.82101
Observations (or Sum Wgts)	3399

t Test: Wednesday-STIR

Assuming equal variances

Difference	2.69951	t Ratio	17.16922
Std Err Dif	0.15723	DF	3397
Upper CL Dif	3.00778	Prob > |t|	<.0001*
Lower CL Dif	2.39123	Prob > t	<.0001*
Confidence	0.95	Prob < t	1.0000



Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Label	1	2698.930	2698.93	294.7822	<.0001*
Error	3397	31101.830	9.16		
C. Total	3398	33800.760			

Means for Oneway Anova

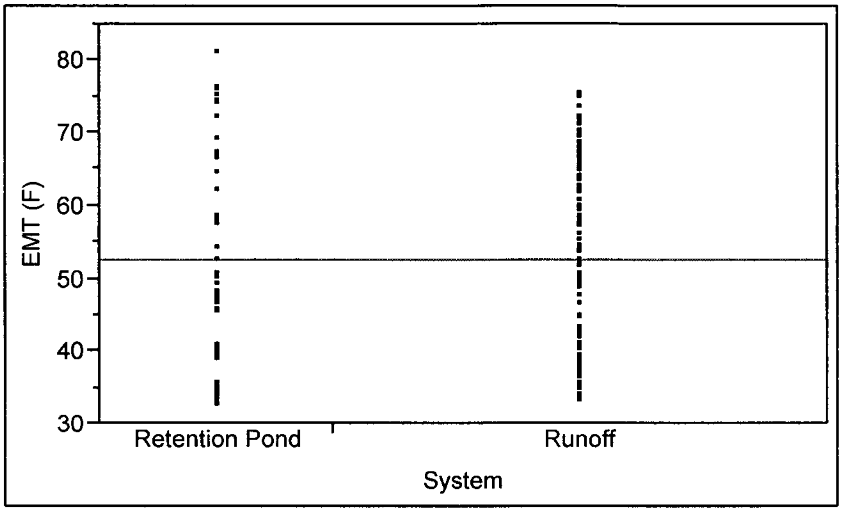
Level	**Number**	**Mean**	**Std Error**	**Lower 95%**	**Upper 95%**
STIR	423	58.4574	0.14712	58.169	58.746
Wednesday	2976	61.1570	0.05547	61.048	61.266

Std Error uses a pooled estimate of error variance

APPENDIX F

MEDIAN EMT STATISTICS
(ANNUAL, SUMMER, WINTER)

Retention Pond (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Retention Pond	56	4492.50	80.2232	-1.471
Runoff	120	11083.5	92.3625	1.471

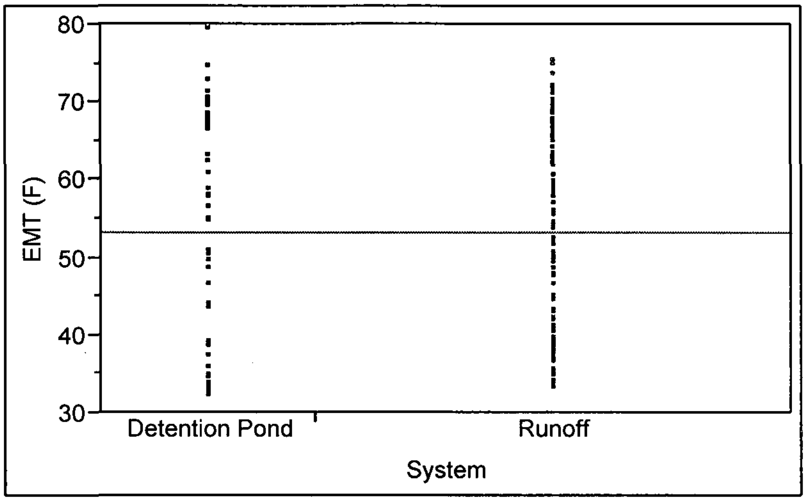
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
4492.5	-1.47067	0.1414

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.1676	1	0.1410

Detention Pond (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Detention Pond	54	4512.50	83.5648	-0.690
Runoff	120	10712.5	89.2708	0.690

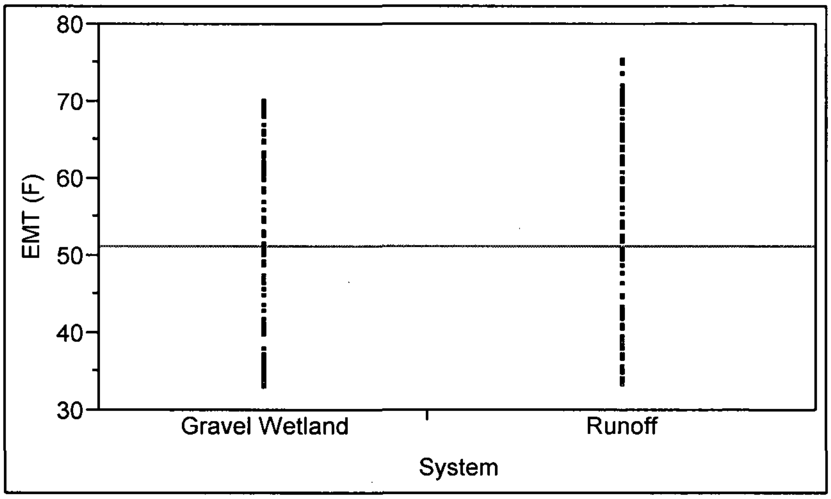
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
4512.5	-0.68966	0.4904

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.4779	1	0.4894

Gravel Wetland (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Gravel Wetland	102	9923.00	97.284	-3.039
Runoff	120	14830.0	123.583	3.039

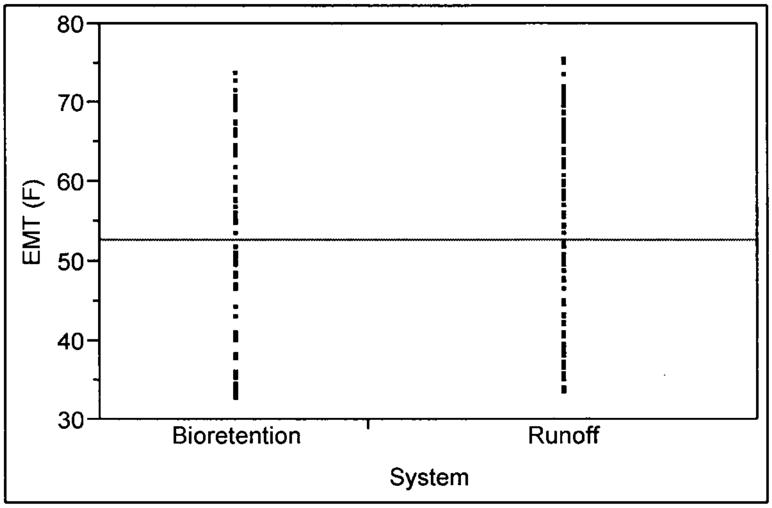
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
9923	-3.03932	0.0024*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.2438	1	0.0024*

Bioretention (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Bioretention	83	8027.50	96.717	-1.064
Runoff	120	12678.5	105.654	1.064

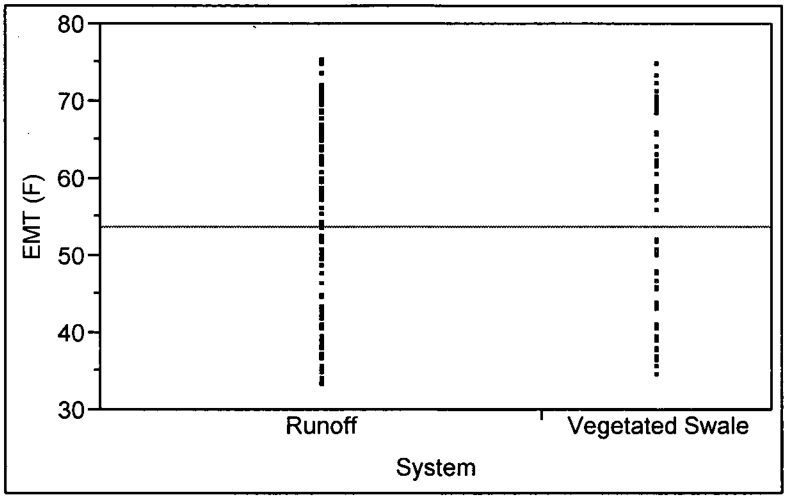
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
8027.5	-1.06446	0.2871

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.1357	1	0.2866

Vegetated Swale (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	120	10844.0	90.3667	-0.574
Vegetated Swale	63	5992.00	95.1111	0.574

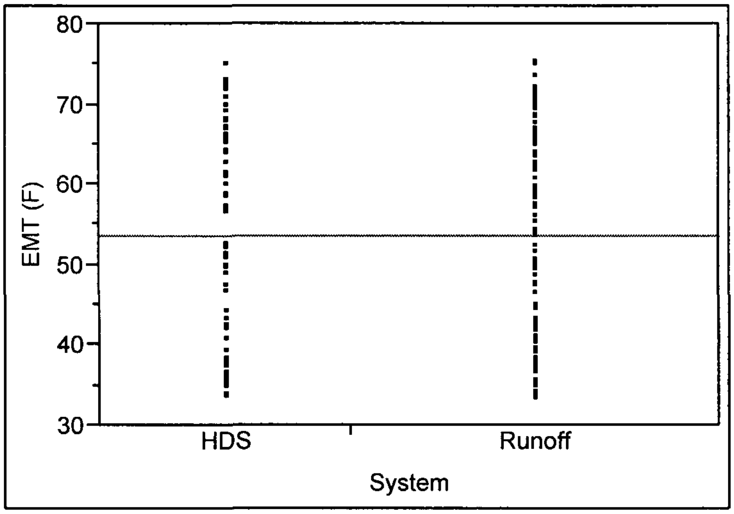
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
5992	0.57422	0.5658

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.3314	1	0.5648

Hydrodynamic Separators (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
HDS	82	8409.50	102.555	0.211
Runoff	120	12093.5	100.779	-0.211

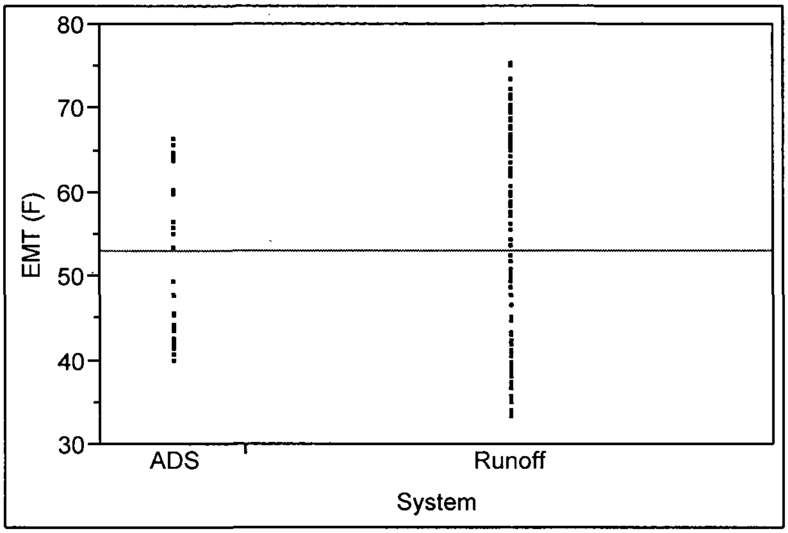
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
8409.5	0.21079	0.8331

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.0450	1	0.8321

ADS Infiltration System (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
ADS	33	2354.50	71.3485	-0.825
Runoff	120	9426.50	78.5542	0.825

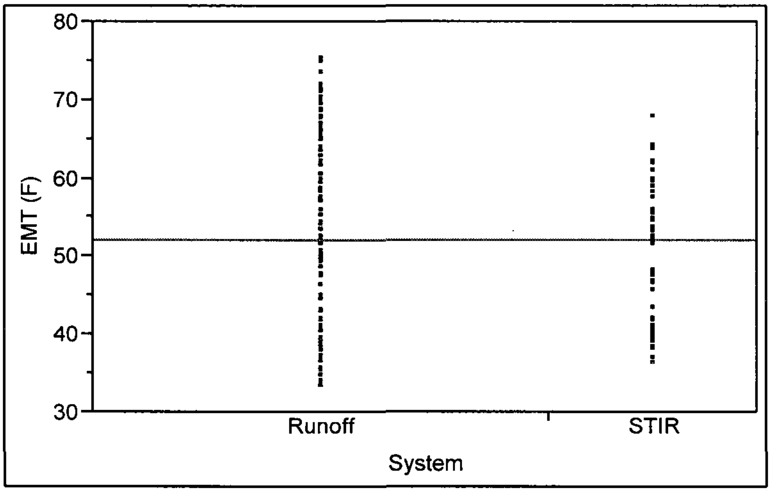
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
2354.5	-0.82511	0.4093

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.6845	1	0.4081

StormTech Isolator Row (Annual)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	120	11221.0	93.5083	2.123
STIR	55	4179.00	75.9818	-2.123

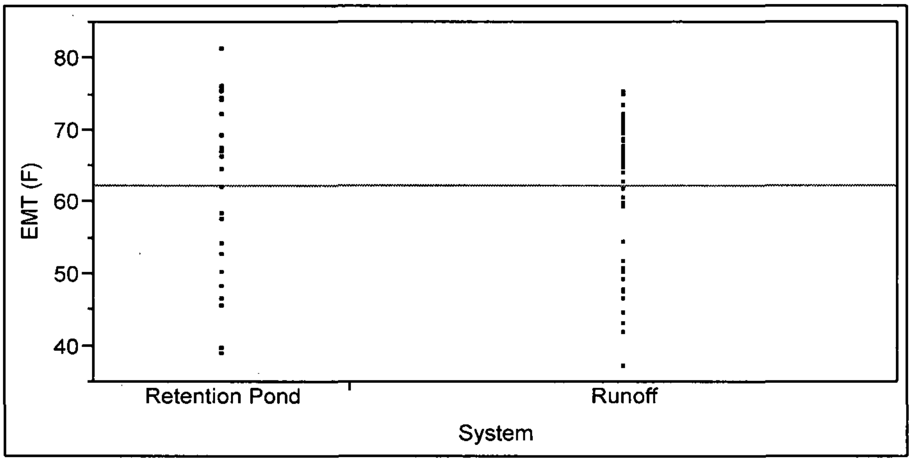
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
4179	-2.12300	0.0338*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.5140	1	0.0336*

Retention Pond (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Retention Pond	27	1135.50	42.0556	-0.236
Runoff	58	2519.50	43.4397	0.236

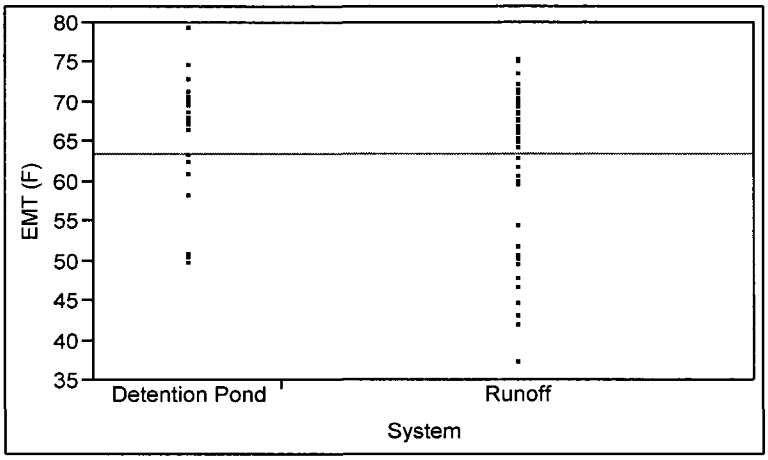
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1135.5	-0.23602	0.8134

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.0580	1	0.8098

Detention Pond (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Detention Pond	23	1093.50	47.5435	1.571
Runoff	58	2227.50	38.4052	-1.571

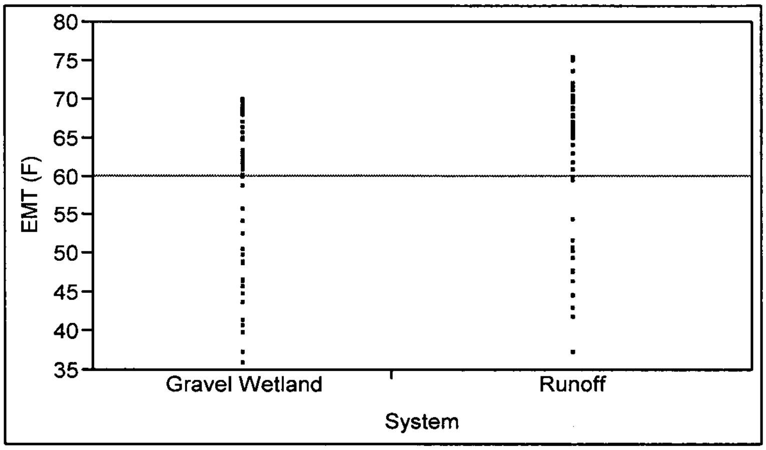
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1093.5	1.57132	0.1161

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.4855	1	0.1149

Gravel Wetland (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Gravel Wetland	48	2089.50	43.5313	-3.034
Runoff	58	3581.50	61.7500	3.034

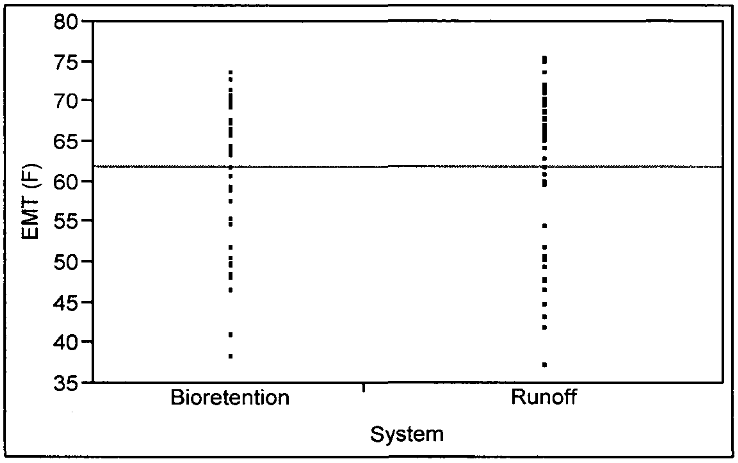
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
2089.5	-3.03406	0.0024*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.2248	1	0.0024*

Bioretention (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Bioretention	44	2072.00	47.0909	-1.308
Runoff	58	3181.00	54.8448	1.308

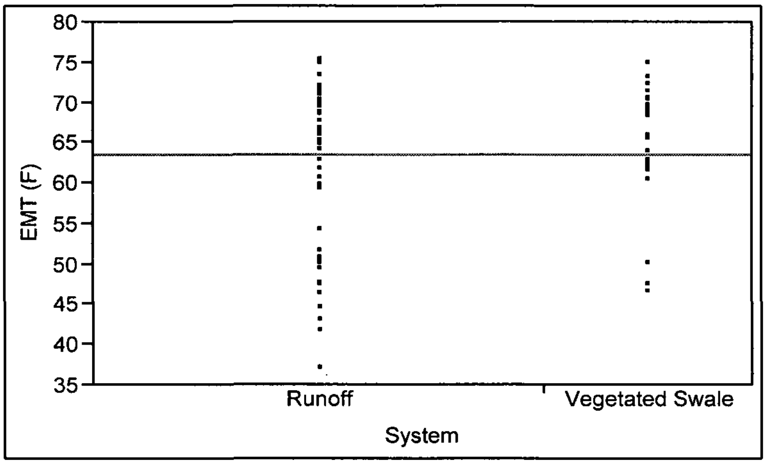
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
2072	-1.30752	0.1910

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.7185	1	0.1899

Vegetated Swale (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	58	2378.50	41.0086	-1.086
Vegetated Swale	27	1276.50	47.2778	1.086

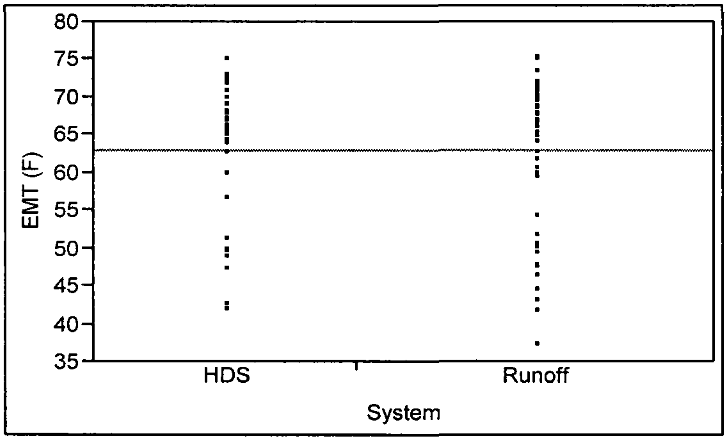
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1276.5	1.08566	0.2776

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.1889	1	0.2755

Hydrodynamic Separator (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
HDS	43	2264.00	52.6512	0.484
Runoff	58	2887.00	49.7759	-0.484

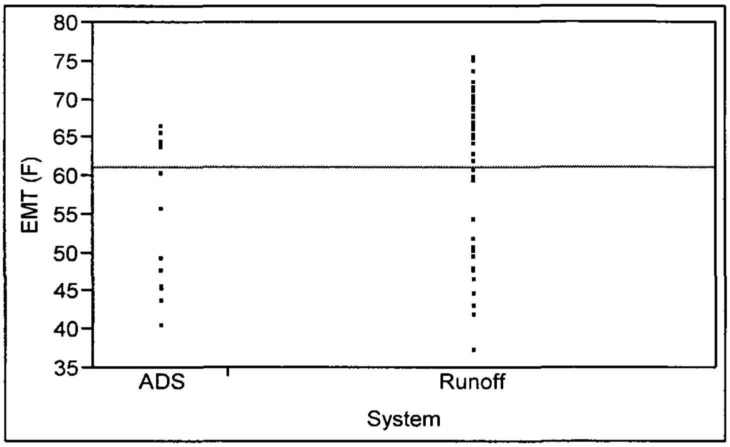
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
2264	0.48425	0.6282

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.2378	1	0.6258

ADS Infiltration System (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
ADS	16	382.000	23.8750	-2.856
Runoff	58	2393.00	41.2586	2.856

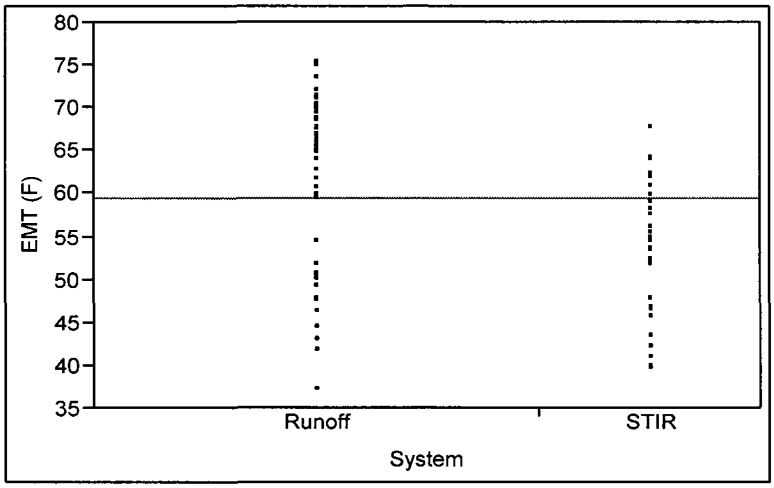
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
382	-2.85627	0.0043*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.1959	1	0.0042*

StormTech Isolator Row (Summer)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	58	3025.00	52.1552	4.255
STIR	29	803.000	27.6897	-4.255

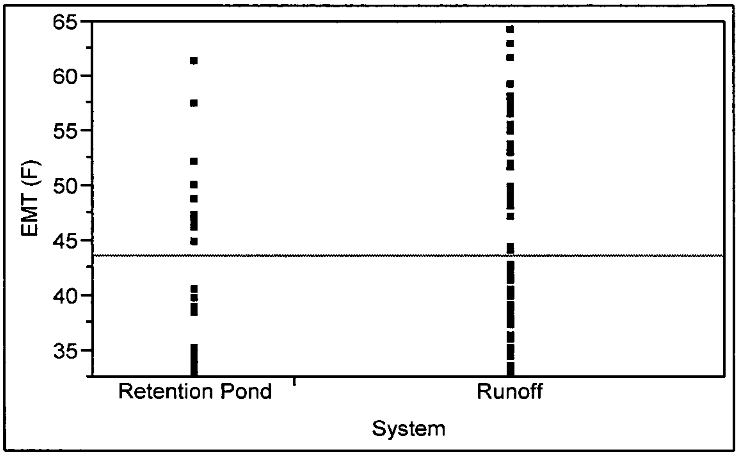
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
803	-4.25473	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
18.1410	1	<.0001*

Retention Pond (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Retention Pond	29	1028.50	35.4655	-2.598
Runoff	62	3157.50	50.9274	2.598

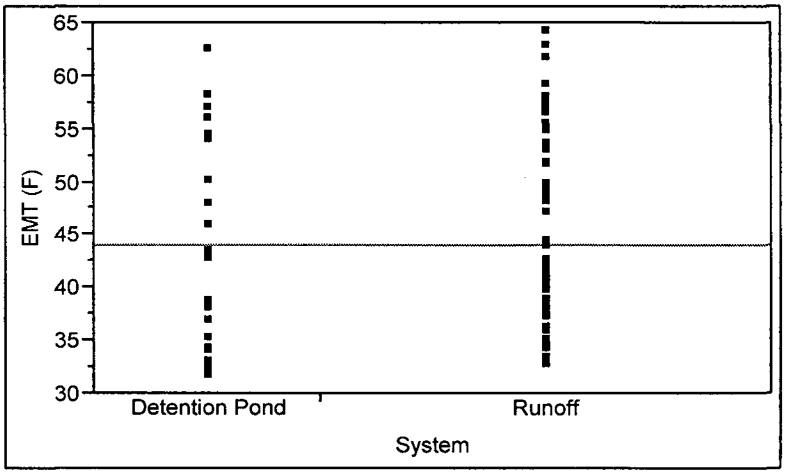
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1028.5	-2.59802	0.0094*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.7719	1	0.0093*

Detention Pond (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Detention Pond	31	1200.00	38.7097	-2.091
Runoff	62	3171.00	51.1452	2.091

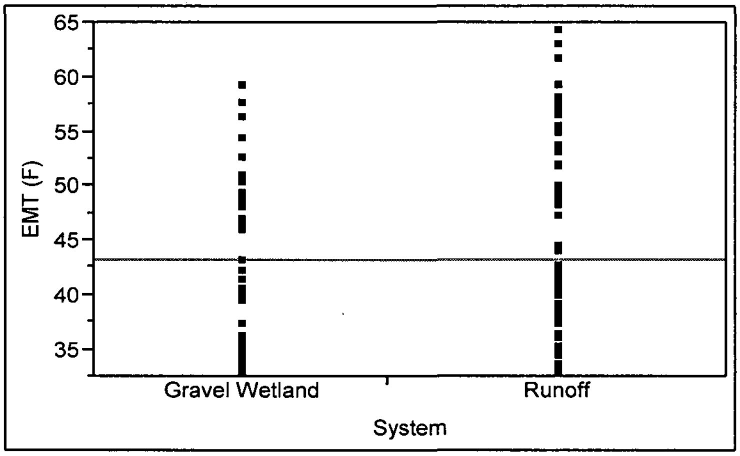
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1200	-2.09059	0.0366*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.3876	1	0.0362*

Gravel Wetland (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Gravel Wetland	54	2623.50	48.5833	-2.961
Runoff	62	4162.50	67.1371	2.961

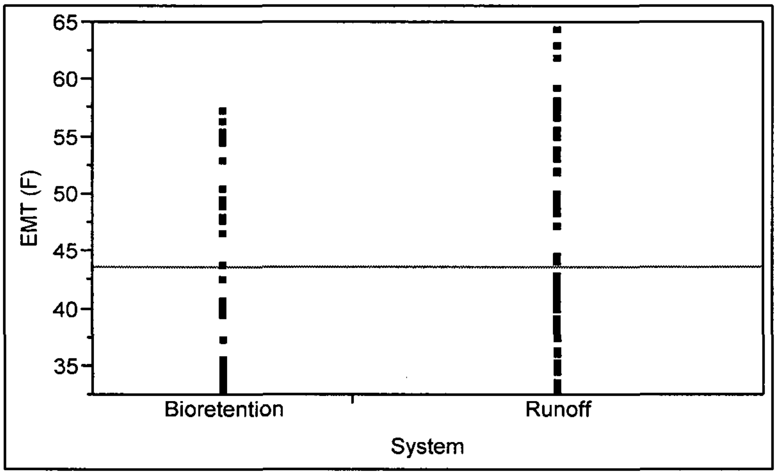
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
2623.5	-2.96139	0.0031*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.7862	1	0.0030*

Bioretention (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Bioretention	39	1641.50	42.0897	-2.421
Runoff	62	3509.50	56.6048	2.421

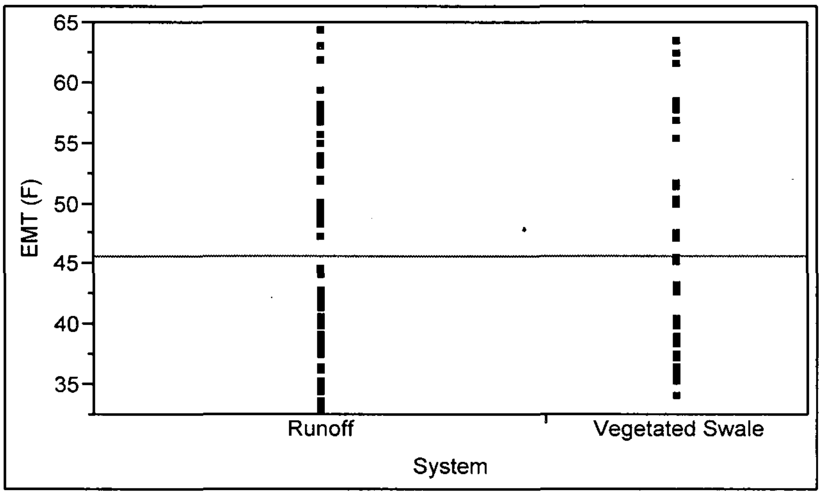
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1641.5	-2.42061	0.0155*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.8762	1	0.0153*

Vegetated Swale (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	62	2960.50	47.7500	-0.796
Vegetated Swale	36	1890.50	52.5139	0.796

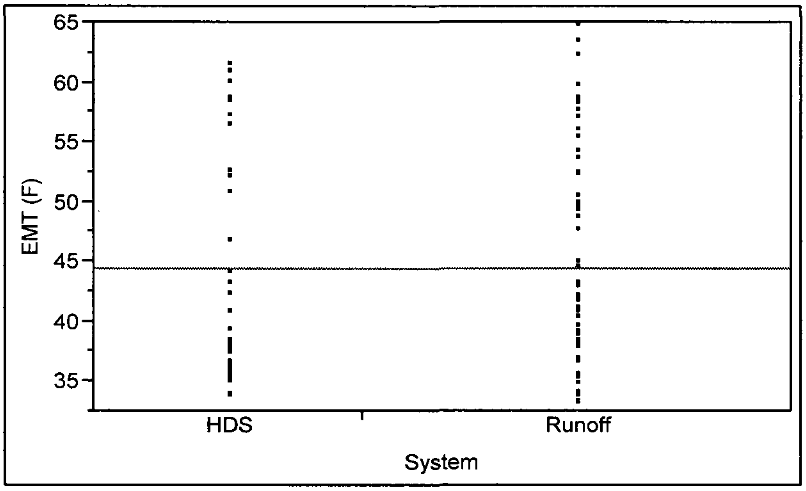
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1890.5	0.79594	0.4261

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.6394	1	0.4239

Hydrodynamic Separators (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
HDS	39	1818.50	46.6282	-1.186
Runoff	62	3332.50	53.7500	1.186

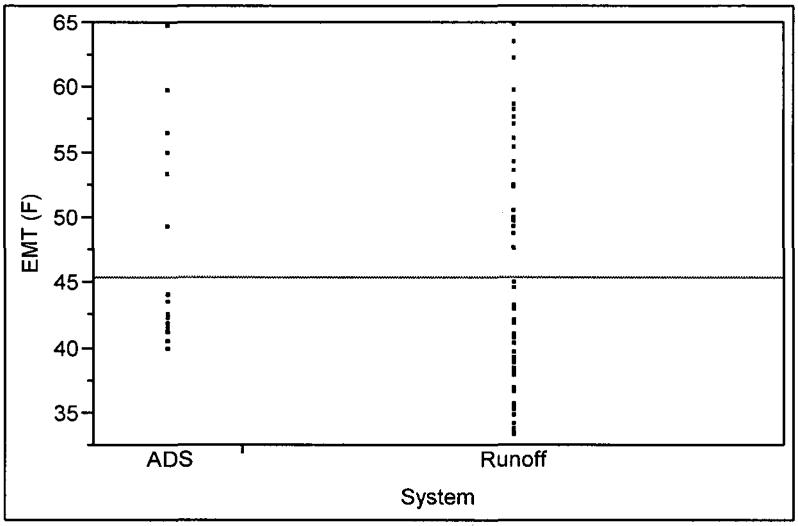
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1818.5	-1.18586	0.2357

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.4146	1	0.2343

ADS Infiltration System (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
ADS	17	778.000	45.7647	1.163
Runoff	62	2382.00	38.4194	-1.163

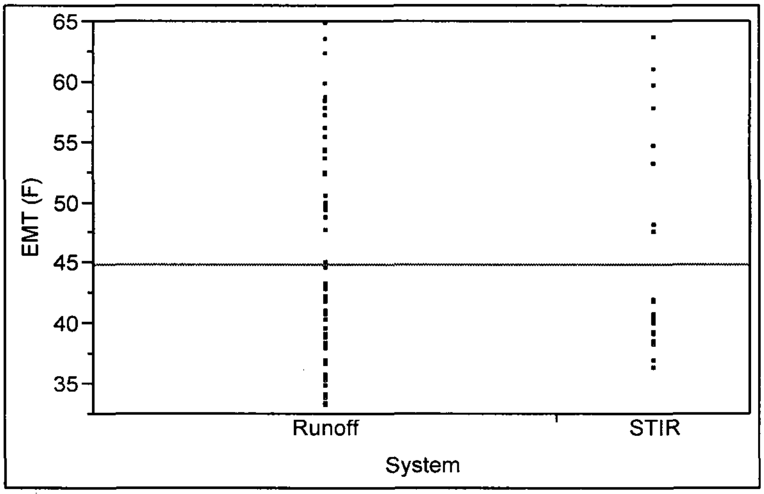
2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
778	1.16321	0.2447

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
1.3670	1	0.2423

StormTech Isolator Row (Winter)



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score Mean	(Mean-Mean0)/Std0
Runoff	62	2786.00	44.9355	0.242
STIR	26	1130.00	43.4615	-0.242

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
1130	-0.24238	0.8085

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
0.0610	1	0.8049

APPENDIX G

SYSTEM CDF STATISTICS
(ANNUAL, SUMMER, WINTER)

Retention Pond (Annual)

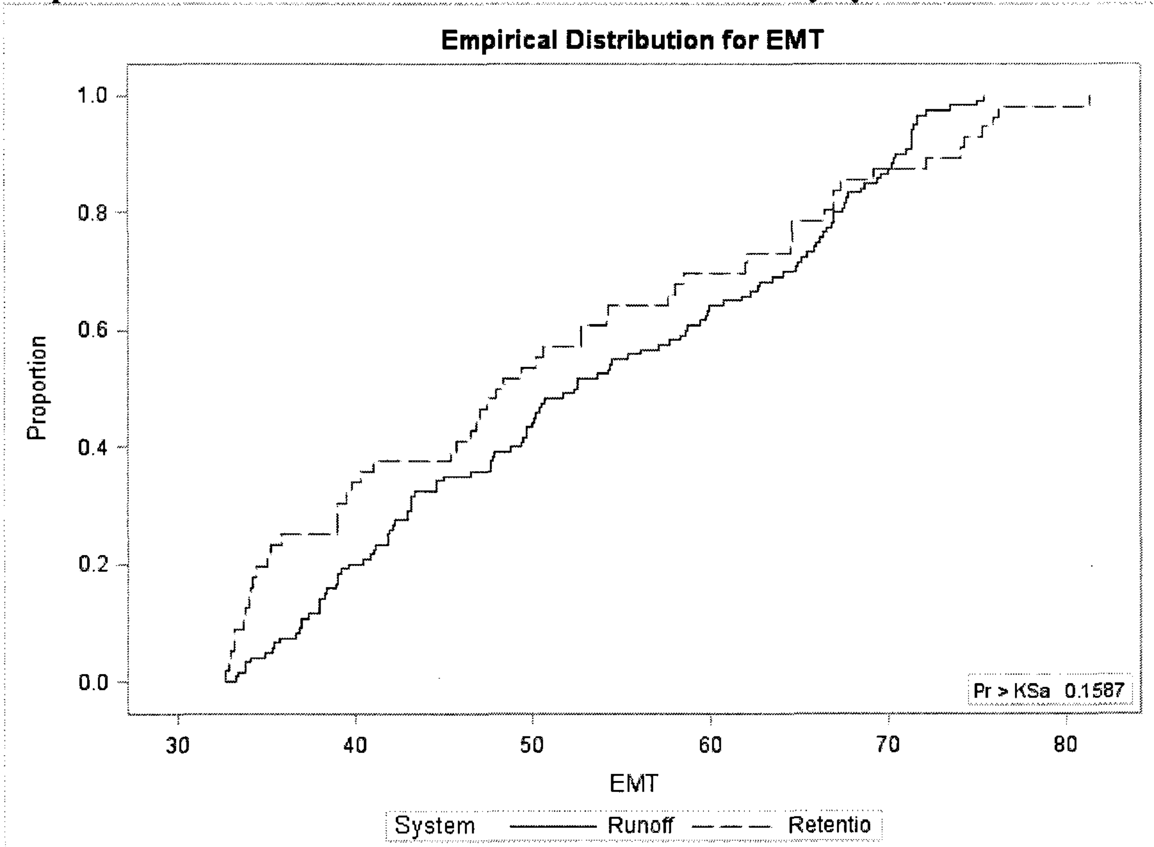
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.05	-0.6349
Retention Pond	56	0.23214	0.92934
Total	176	0.10795	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.084837	D	0.182143
KSa	1.125487	Pr > KSa	0.1587

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Annual)

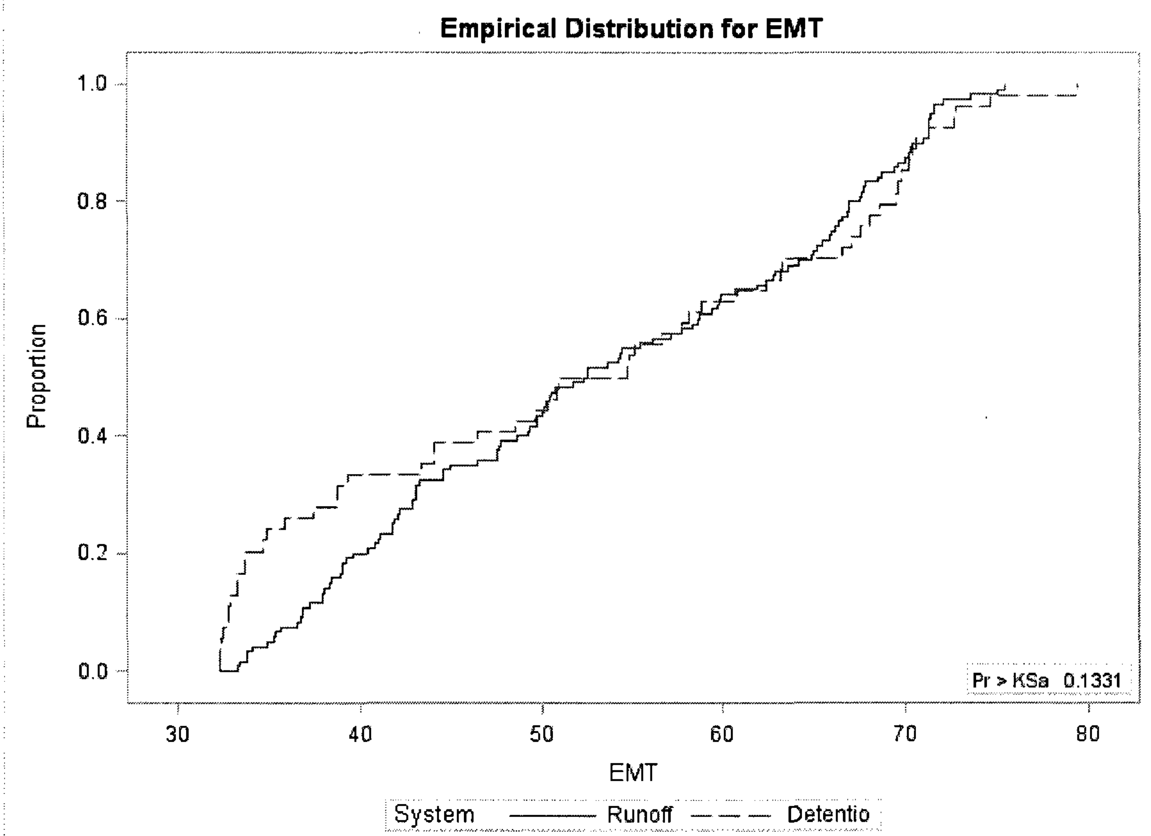
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.05	-0.6485
Detention Pond	54	0.24074	0.96666
Total	174	0.1092	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.088243	D	0.190741
KSa	1.164009	Pr > KSa	0.1331

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

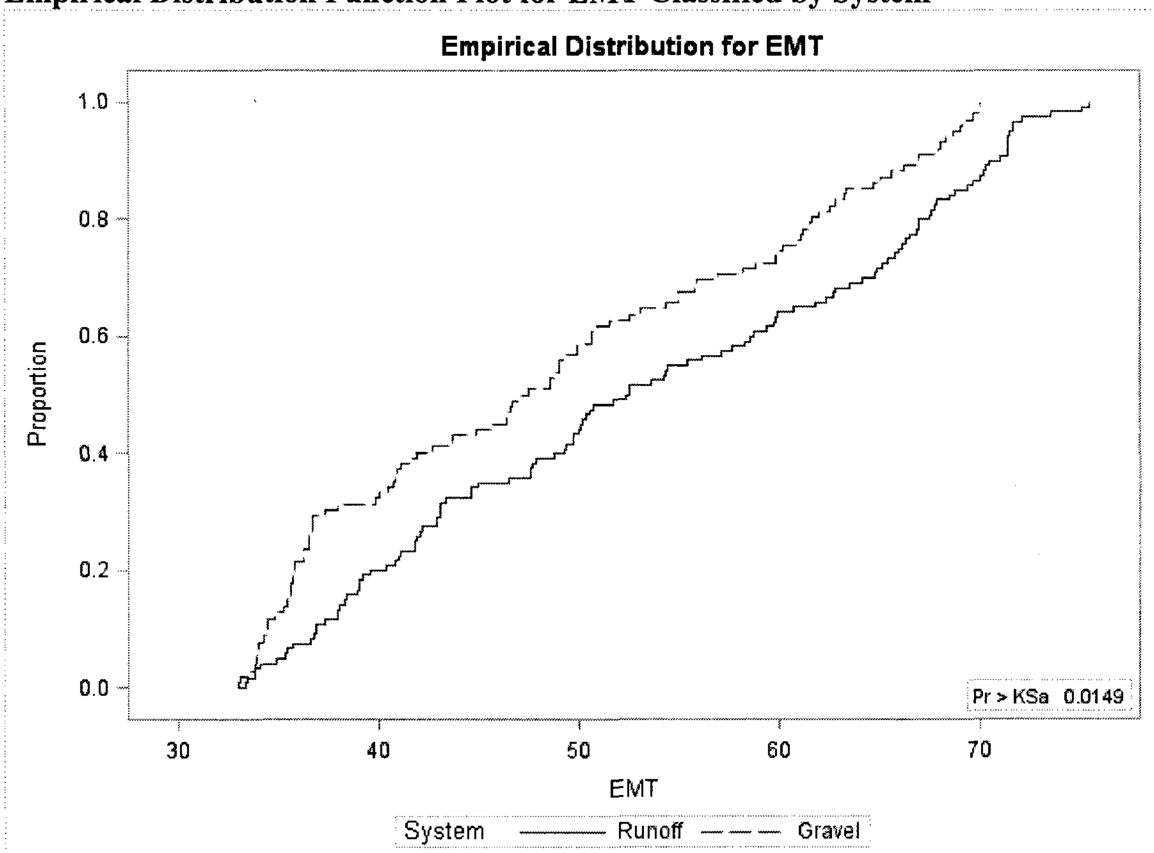
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.08333	-1.0609
Gravel Wetland	102	0.29412	1.15071
Total	222	0.18018	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.105045	D	0.210784
KSa	1.565138	Pr > KSa	0.0149

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

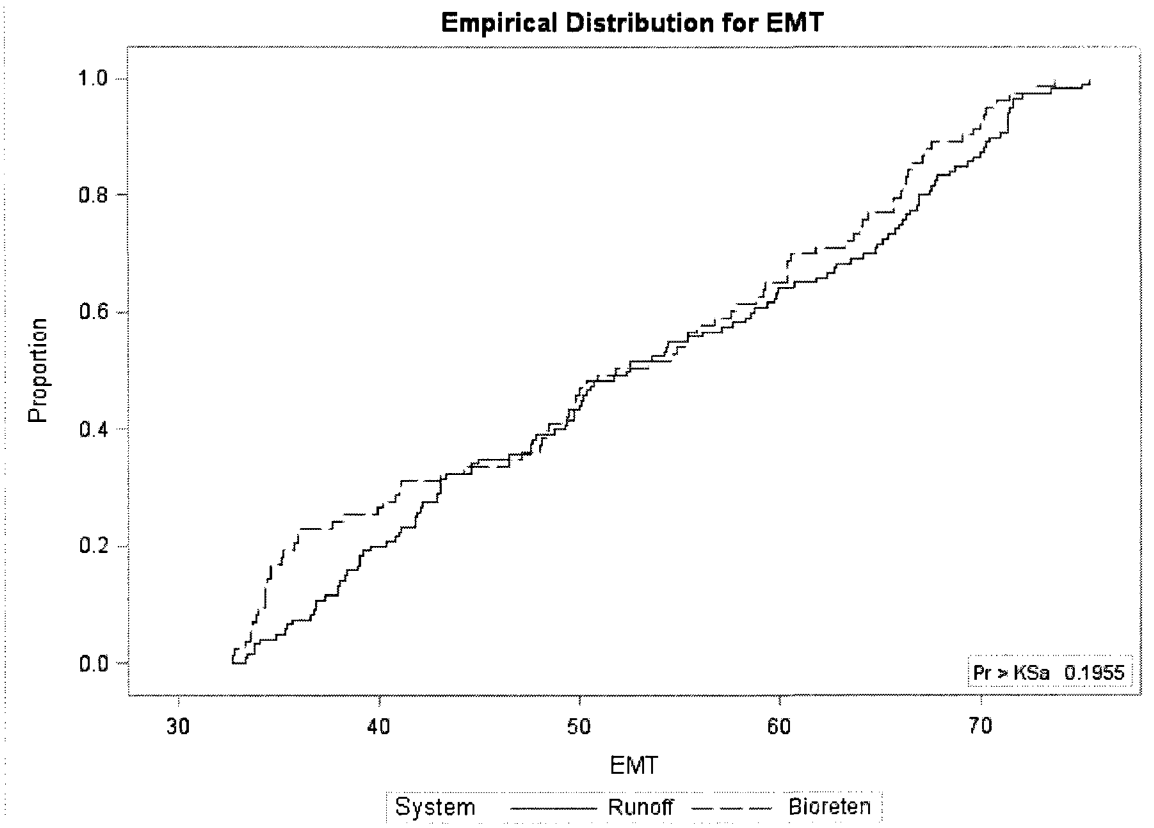
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.075	-0.6894
Bioretention	83	0.22892	0.82891
Total	203	0.13793	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.075669	D	0.153916
KSa	1.078113	Pr > KSa	0.1955

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

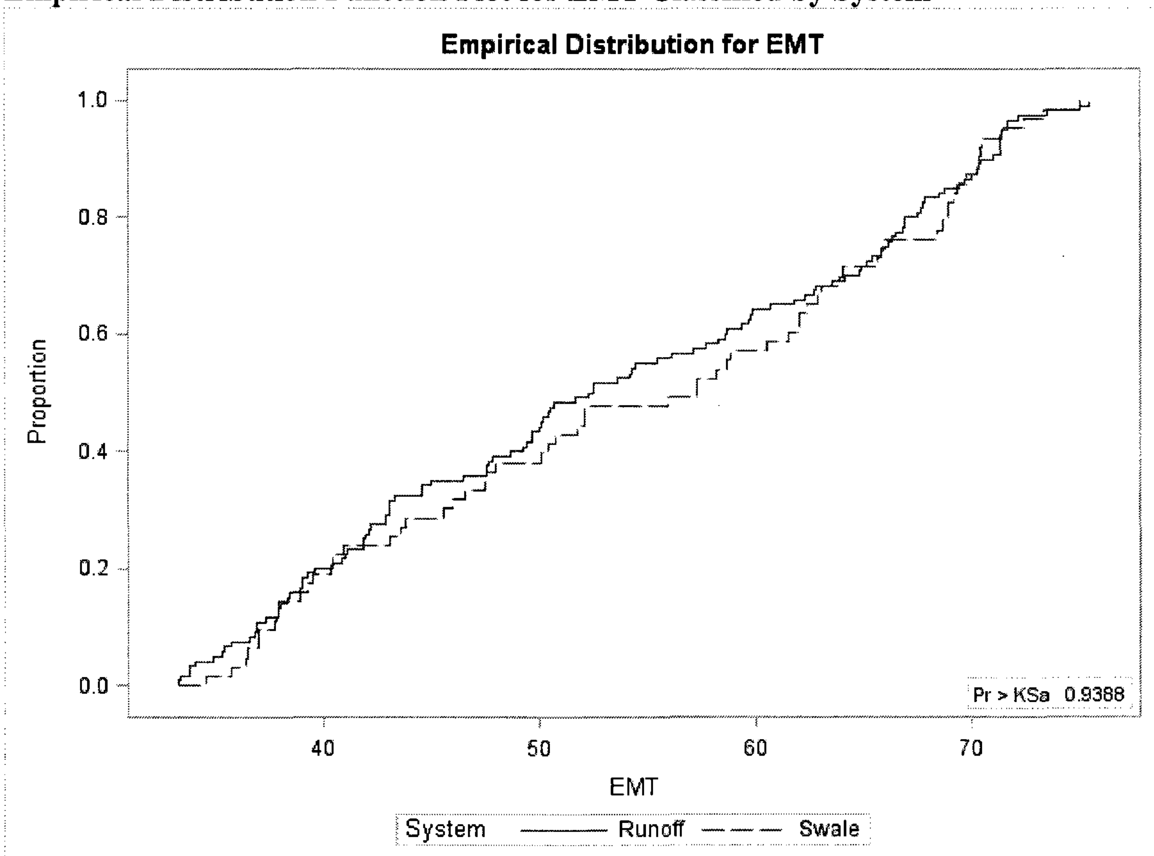
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.575	0.31277
Vegetated Swale	63	0.49206	-0.4317
Total	183	0.54645	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.039405	D	0.082937
KSa	0.533066	Pr > KSa	0.9388

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

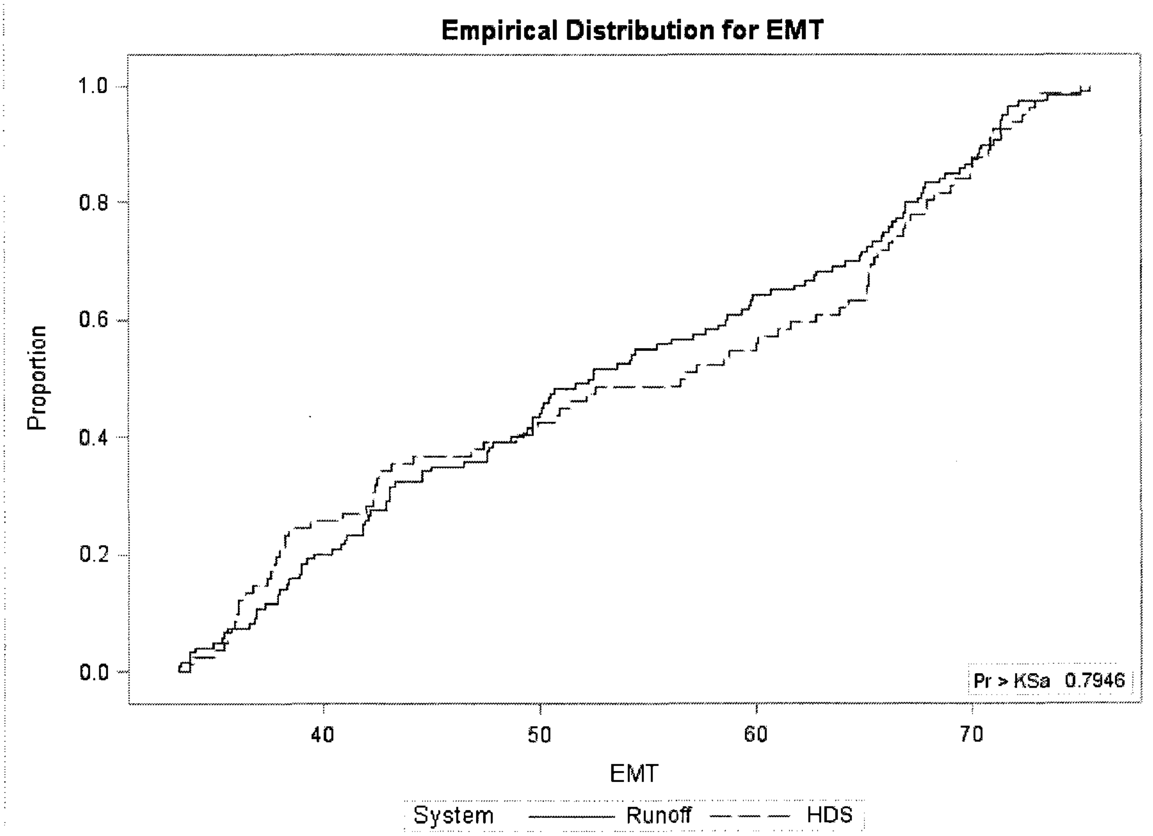
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.64167	0.41305
HDS	82	0.54878	-0.4997
Total	202	0.60396	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.045614	D	0.092886
KSa	0.648295	Pr > KSa	0.7946

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

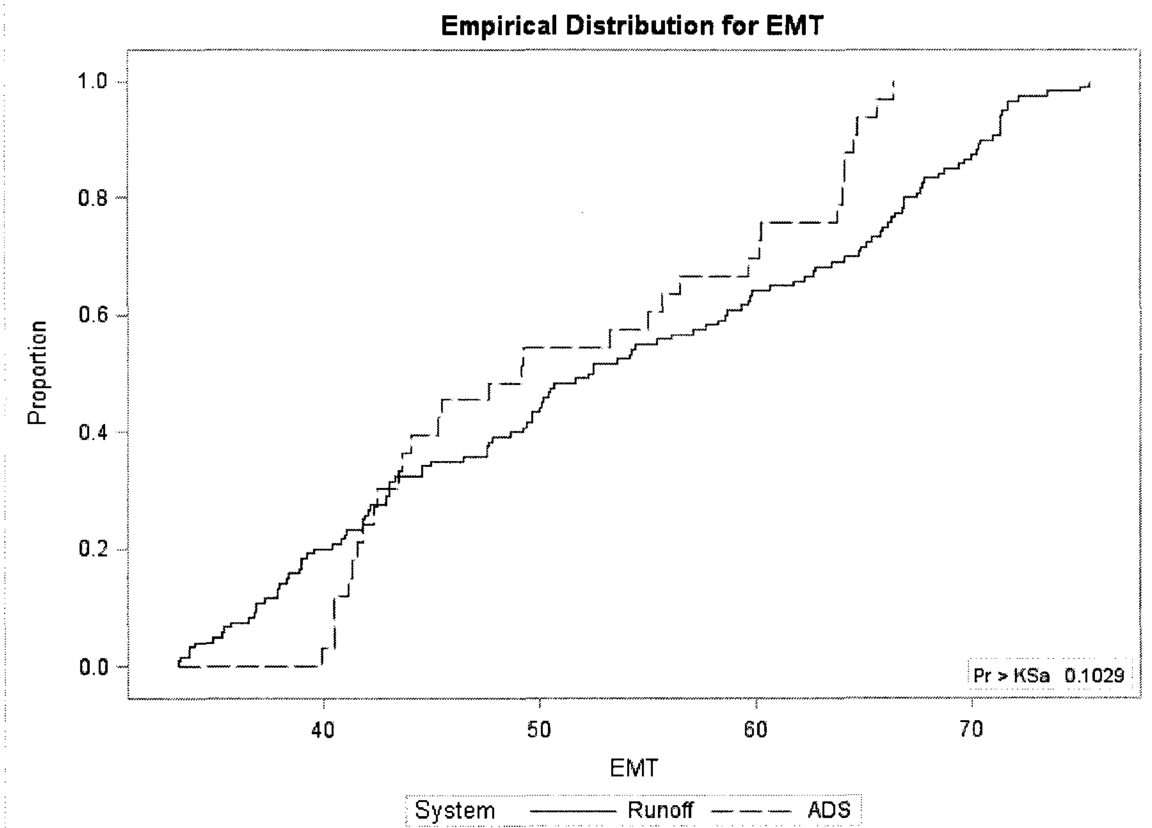
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.7	-0.5656
ADS	33	0.93939	1.0786
Total	153	0.75163	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.098462	D	0.239394
KSa	1.217910	Pr > KSa	0.1029

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

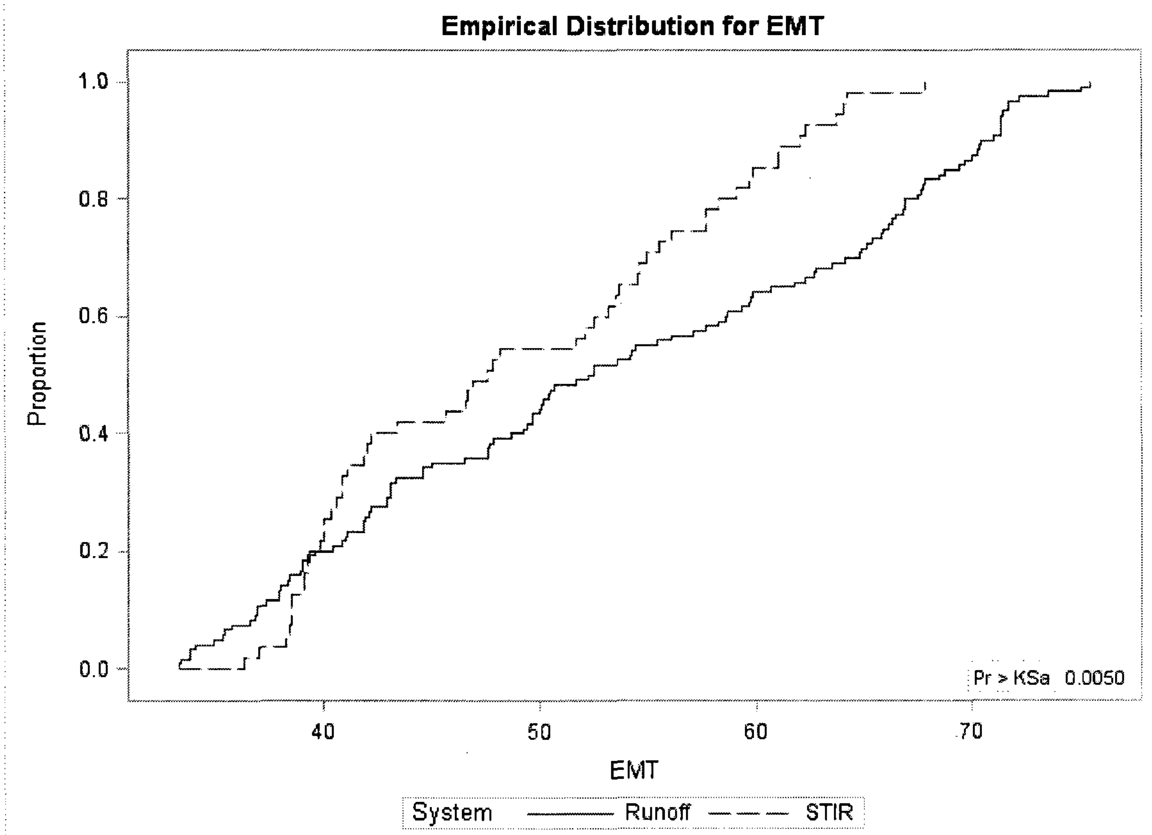
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	120	0.7	-0.9703
STIR	55	0.98182	1.43316
Total	175	0.78857	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.130829	D	0.281818
KSa	1.730701	Pr > KSa	0.0050

Empirical Distribution Function Plot for EMT Classified by System



Retention Pond (Summer)

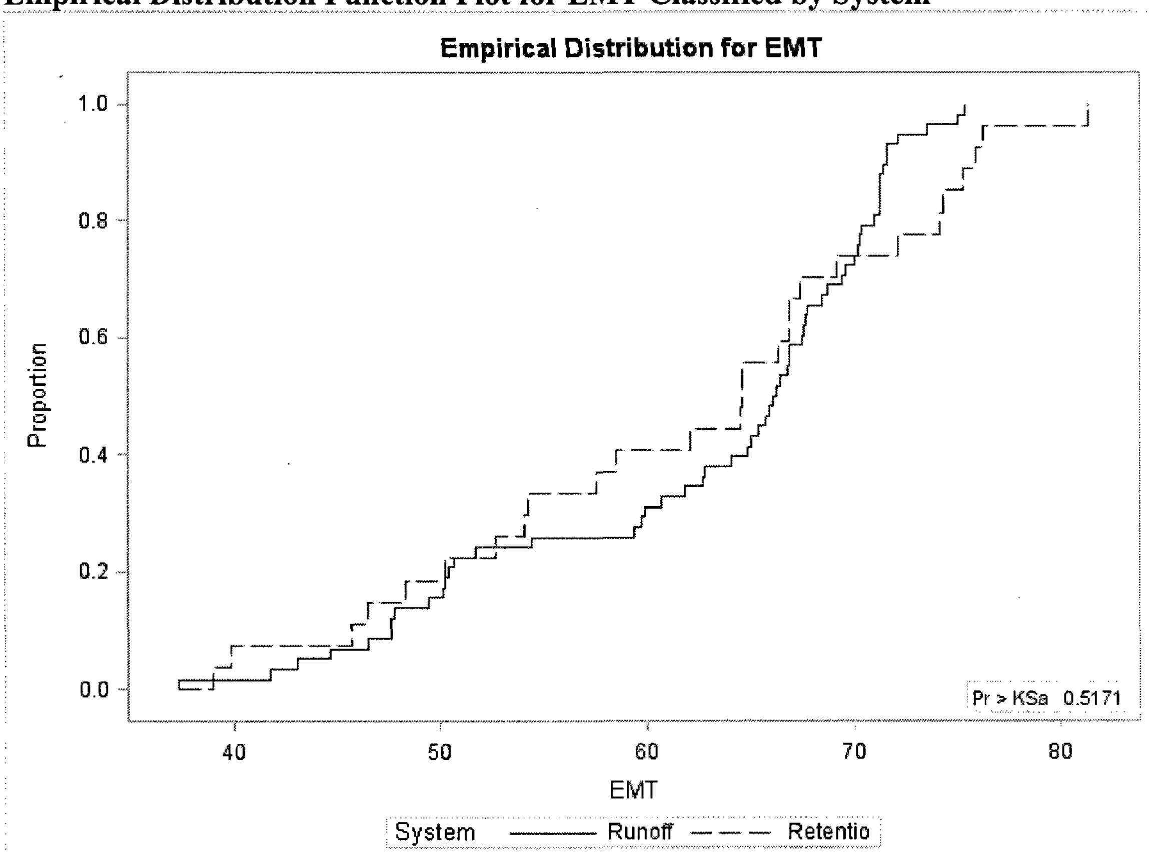
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.93103	0.46034
Retention Pond	27	0.74074	-0.6747
Total	85	0.87059	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.088593	D	0.190294
KSa	0.816791	Pr > KSa	0.5171

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

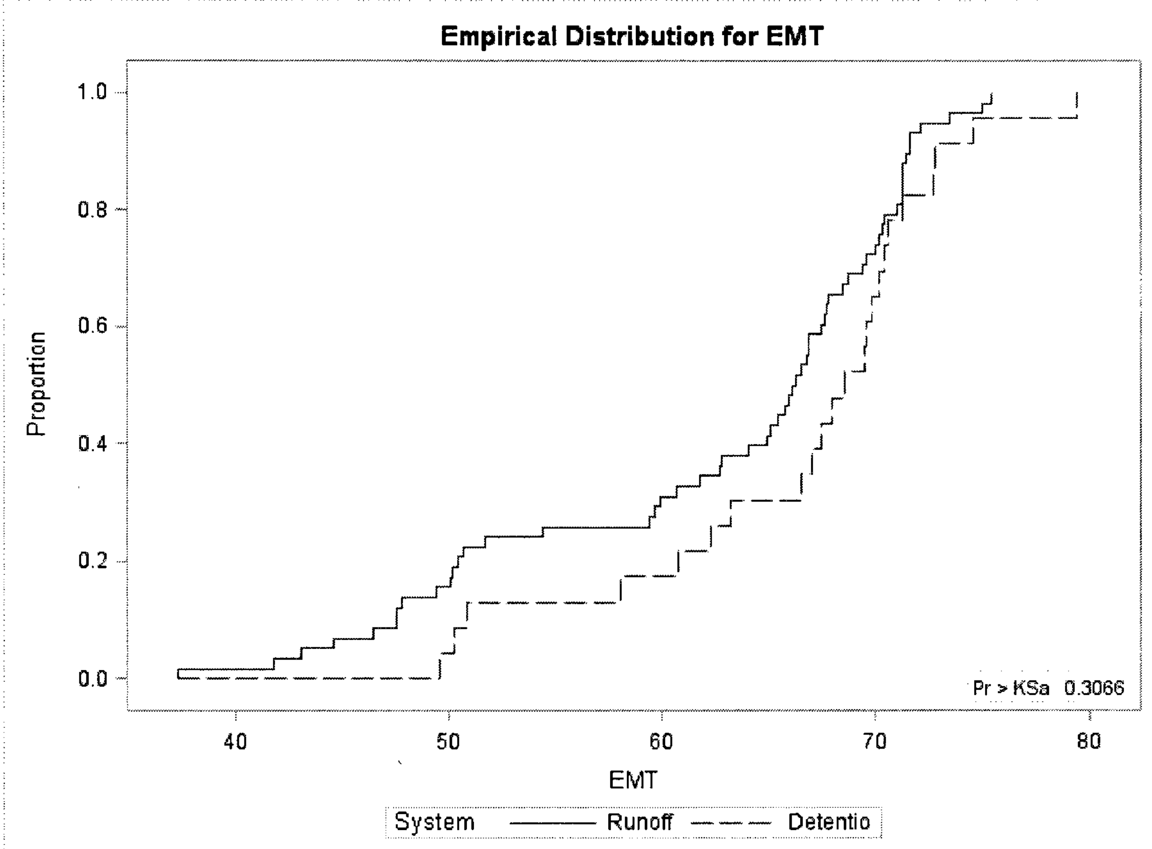
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.58621	0.5155
Detention Pond	23	0.34783	-0.8186
Total	81	0.51852	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.107489	D	0.238381
KSa	0.967401	Pr > KSa	0.3066

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

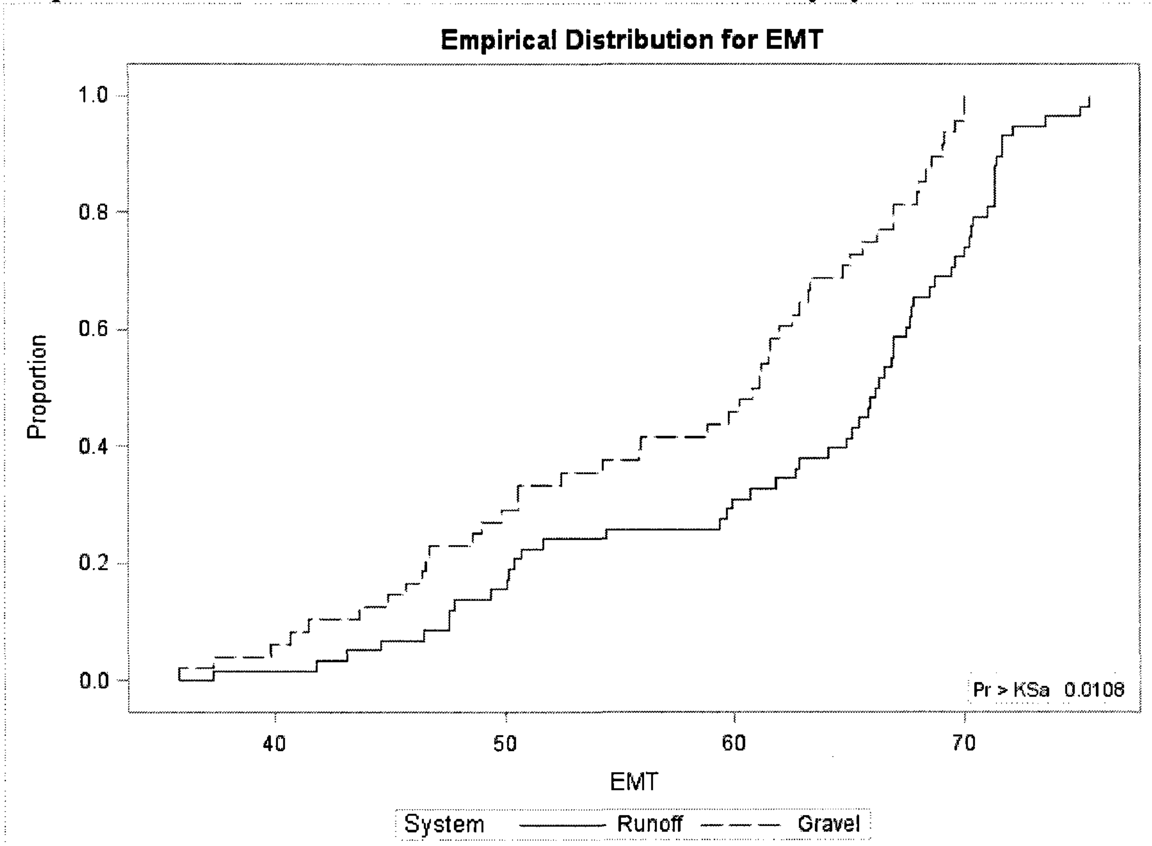
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.41379	-1.0876
Gravel Wetland	48	0.72917	1.19555
Total	106	0.5566	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.156984	D	0.315374
KSa	1.616244	Pr > KSa	0.0108

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

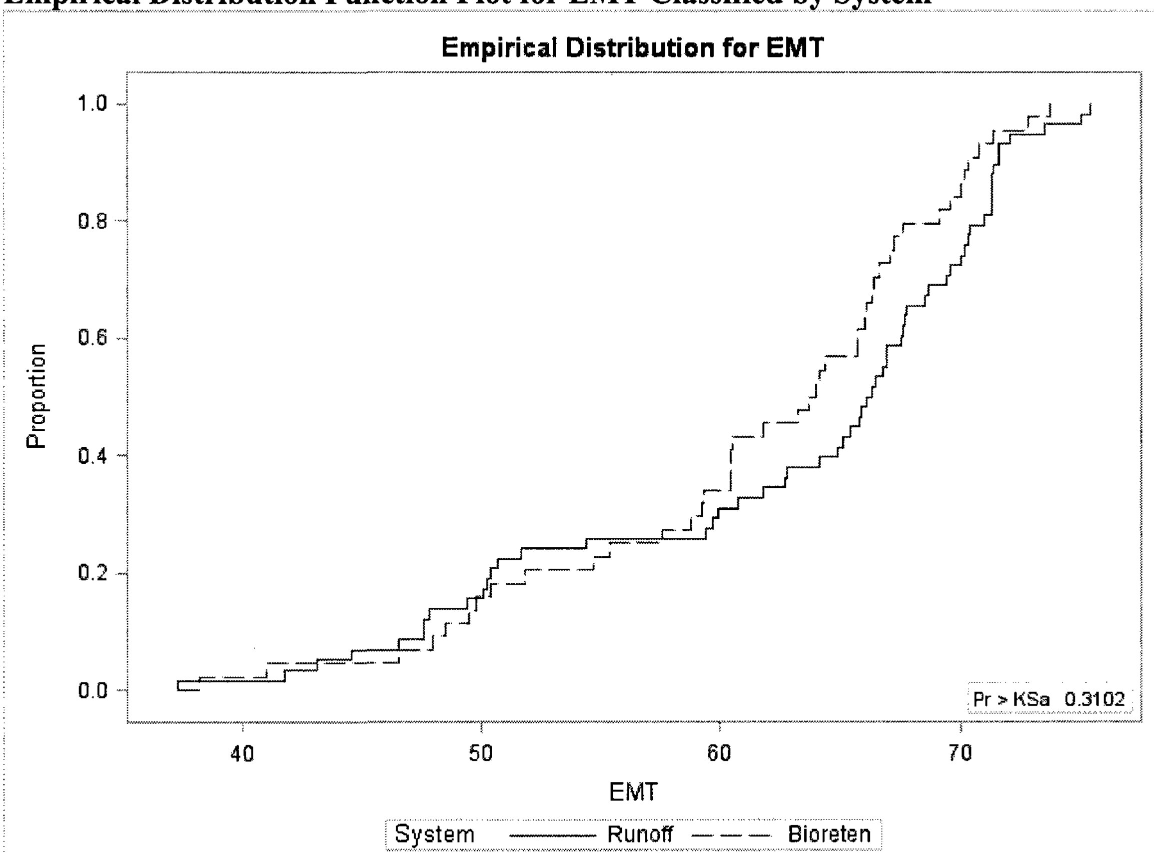
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.53448	-0.6334
Bioretention	44	0.72727	0.72717
Total	102	0.61765	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.095483	D	0.192790
KSa	0.964328	Pr > KSa	0.3102

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

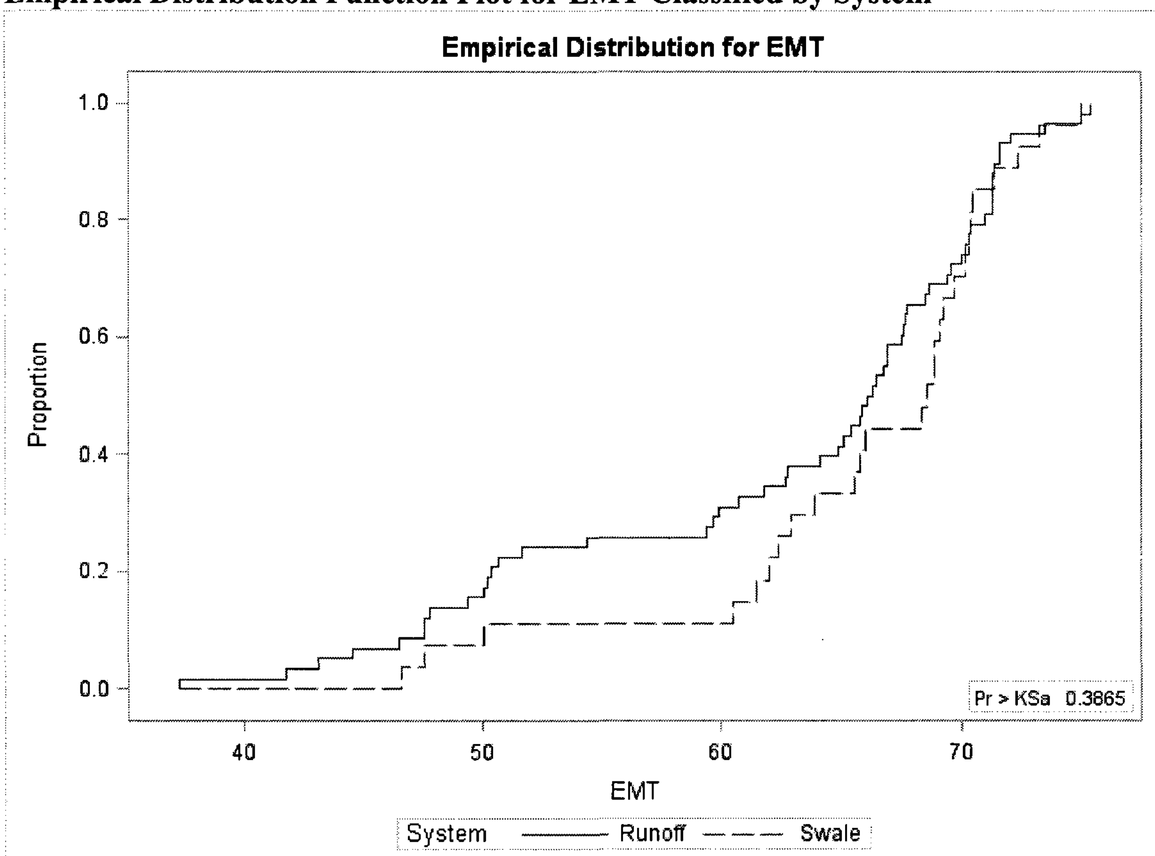
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.65517	0.50978
Vegetated Swale	27	0.44444	-0.7472
Total	85	0.58824	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.098107	D	0.210728
KSa	0.904500	Pr > KSa	0.3865

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

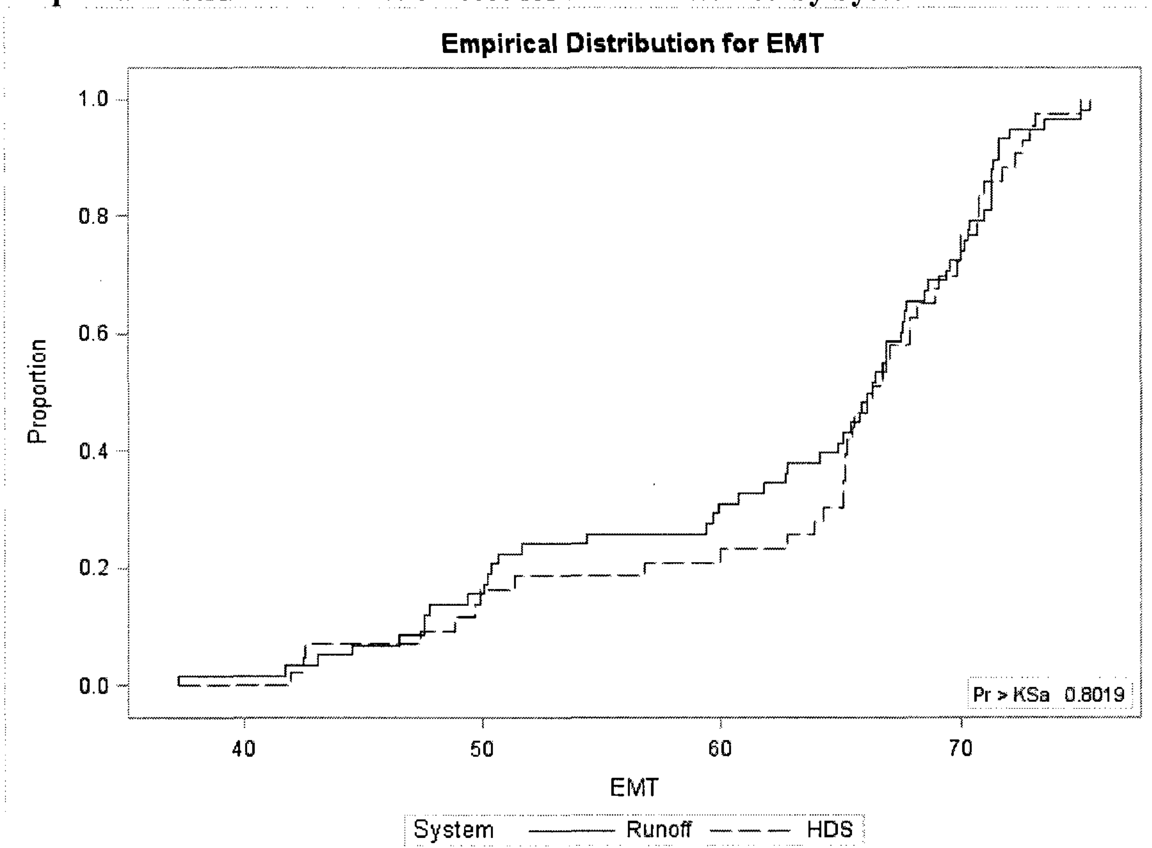
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.36207	0.41992
HDS	43	0.23256	-0.4877
Total	101	0.30693	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.064037	D	0.129511
KSa	0.643567	Pr > KSa	0.8019

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

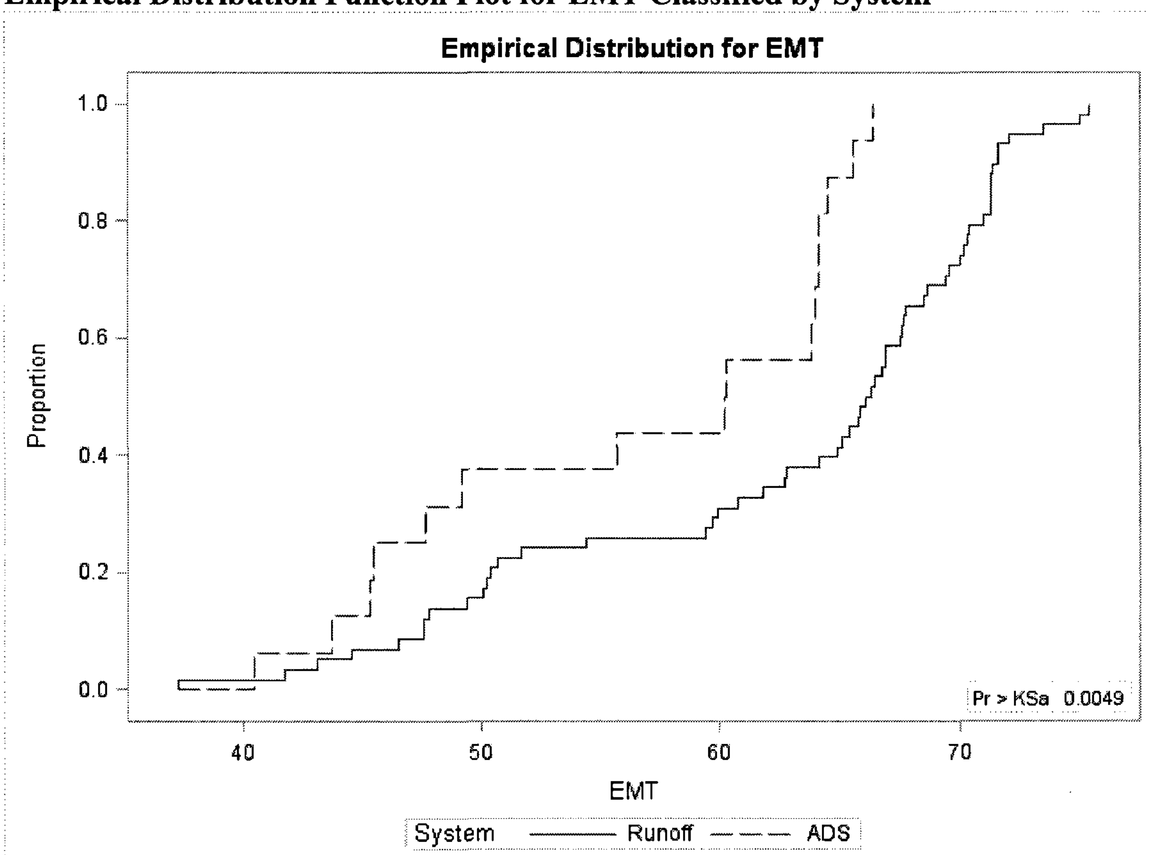
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.44828	-0.8056
ADS	16	0.9375	1.53378
Total	74	0.55405	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.201396	D	0.489224
KSa	1.732471	Pr > KSa	0.0049

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

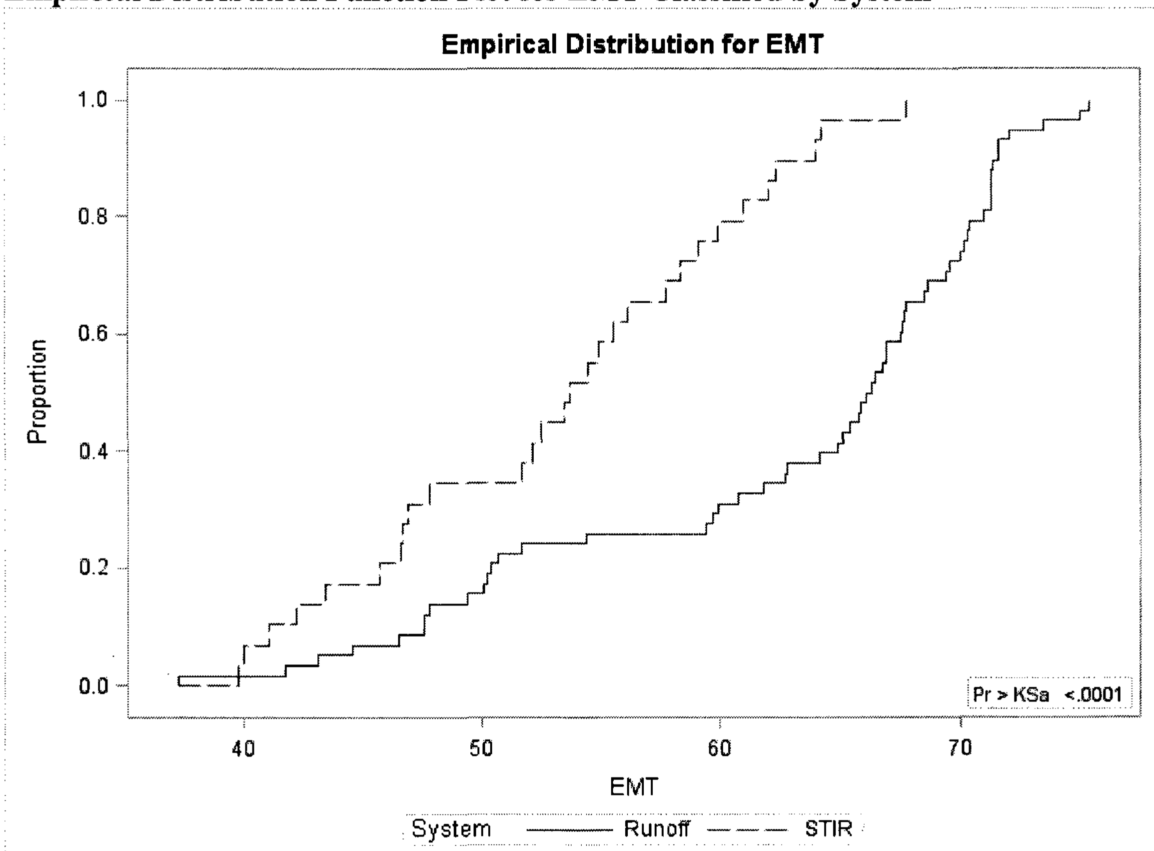
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	58	0.39655	-1.4444
STIR	29	0.96552	2.04265
Total	87	0.58621	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.268213	D	0.568966
KSa	2.501724	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Retention Pond (Winter)

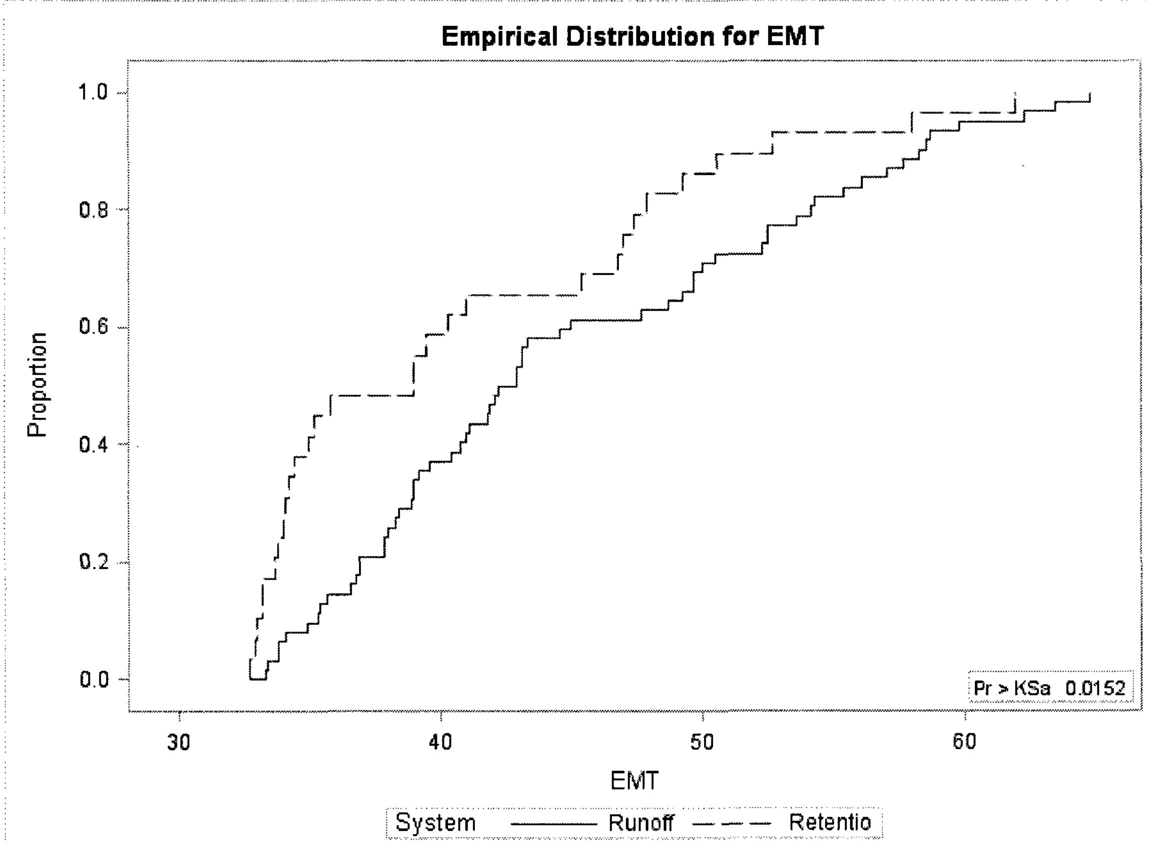
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.09677	-0.882
Retention Pond	29	0.44828	1.28966
Total	91	0.20879	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.163788	D	0.351502
KSa	1.562433	Pr > KSa	0.0152

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond (Winter)

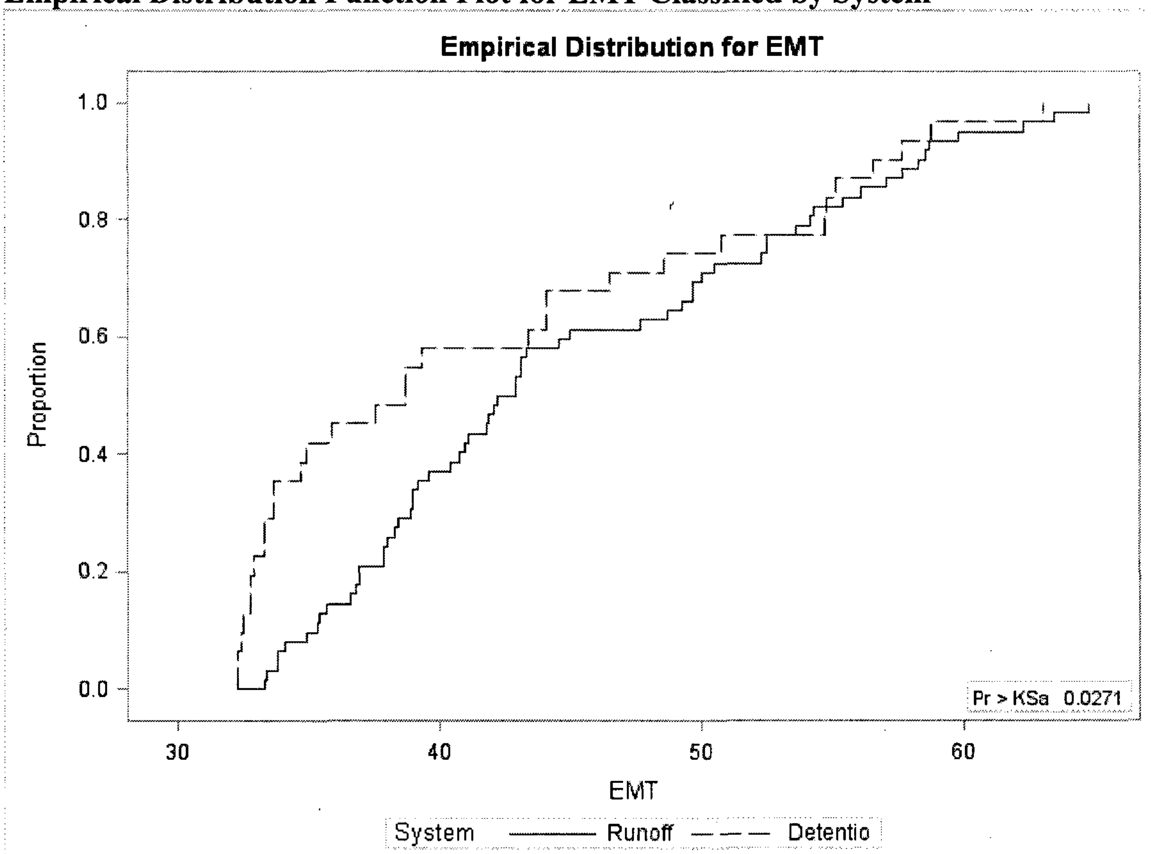
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.03226	-0.8467
Detention Pond	31	0.35484	1.19737
Total	93	0.13978	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.152066	D	0.322581
KSa	1.466471	Pr > KSa	0.0271

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

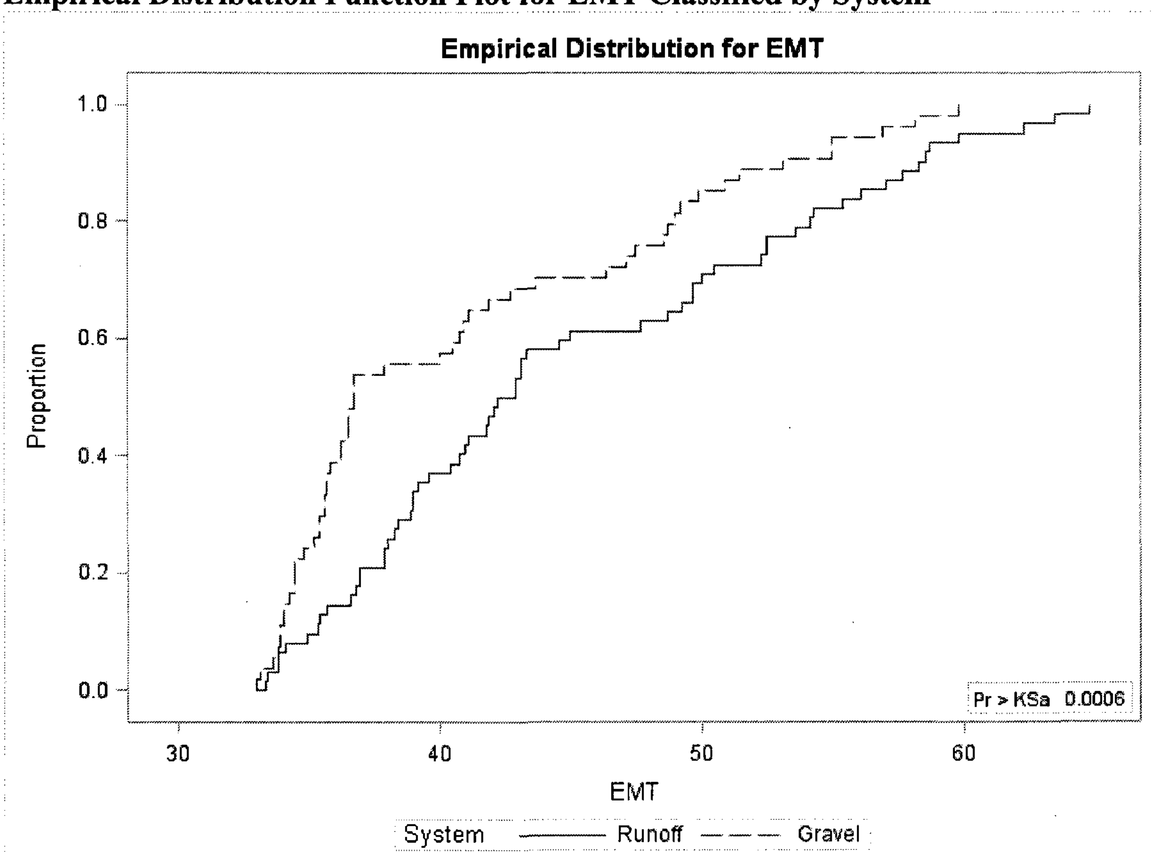
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.16129	-1.3773
Gravel Wetland	54	0.53704	1.47579
Total	116	0.33621	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.187426	D	0.375747
KSa	2.018640	Pr > KSa	0.0006

Empirical Distribution Function Plot for EMT Classified by System



Bioretention (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

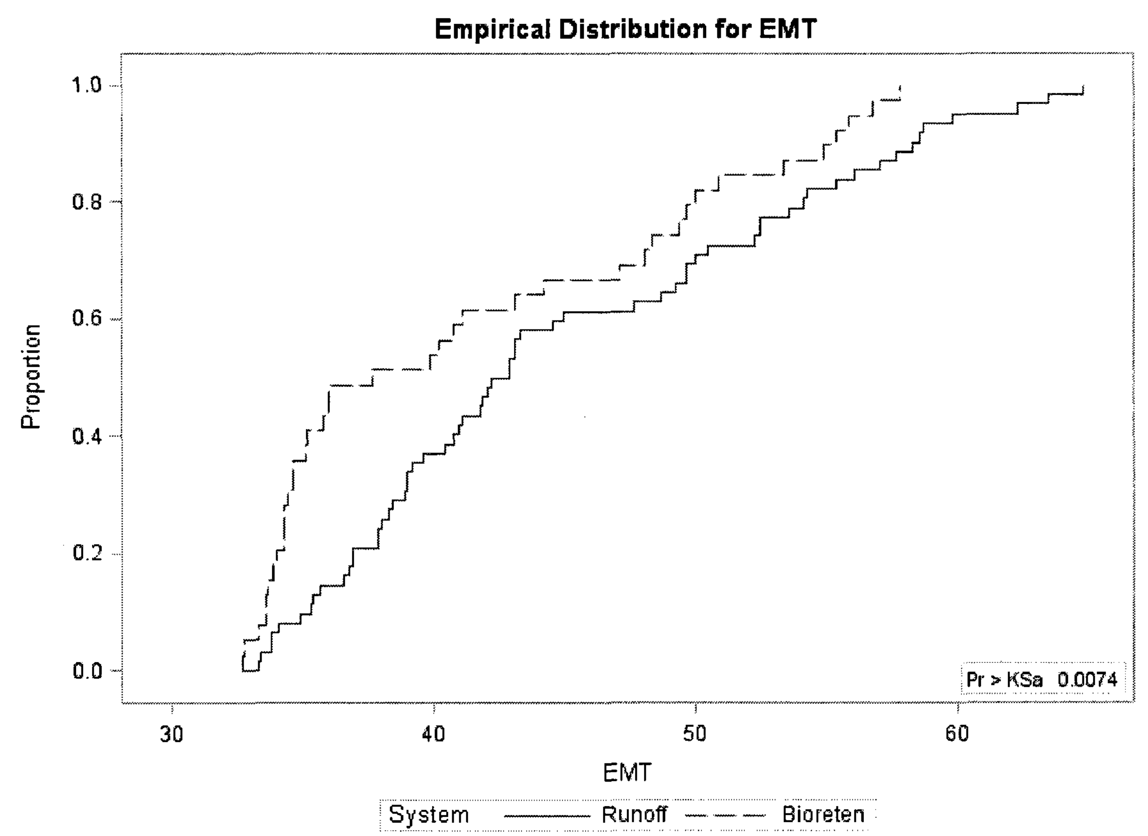
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.14516	-1.0399
Bioretention	39	0.48718	1.31115
Total	101	0.27723	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.166516	D	0.342018
KSa	1.673465	Pr > KSa	0.0074

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

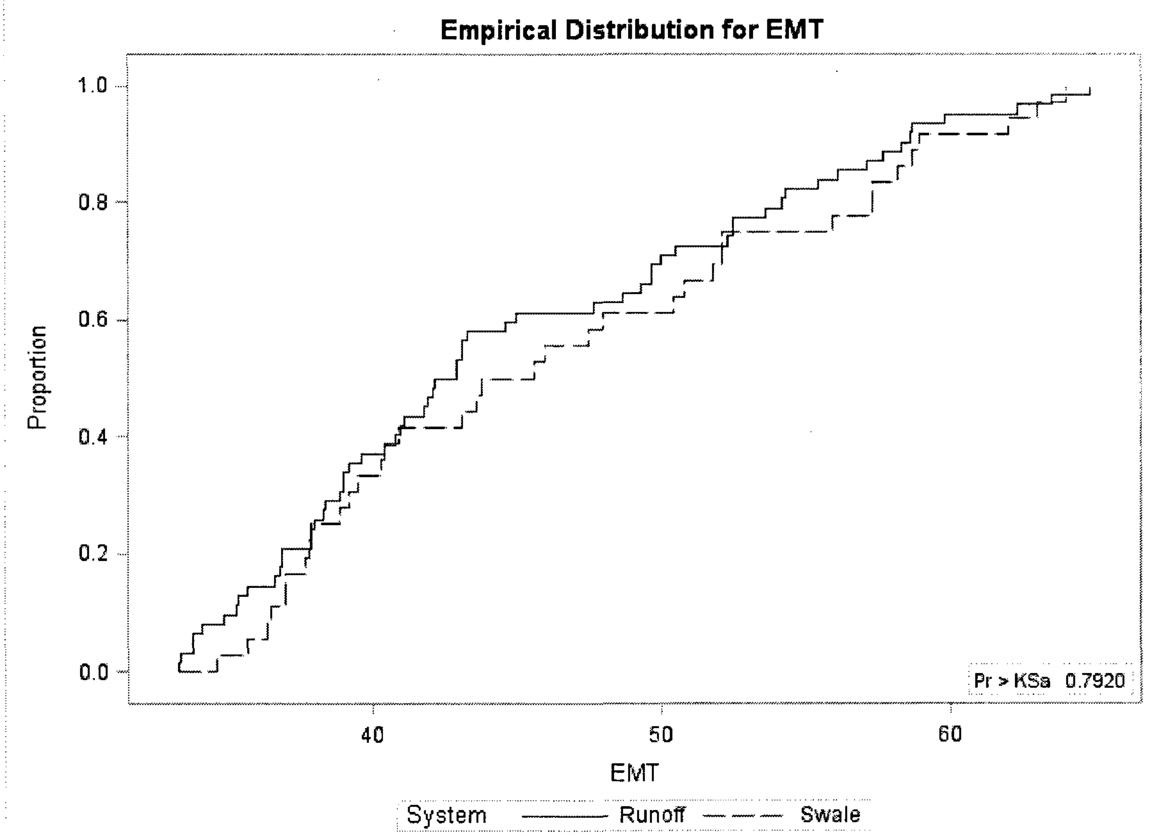
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.58065	0.39396
Vegetated Swale	36	0.44444	-0.517
Total	98	0.53061	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.065660	D	0.136201
KSa	0.650000	Pr > KSa	0.7920

Empirical Distribution Function Plot for EMT Classified by System



Hydrodynamic Separators (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

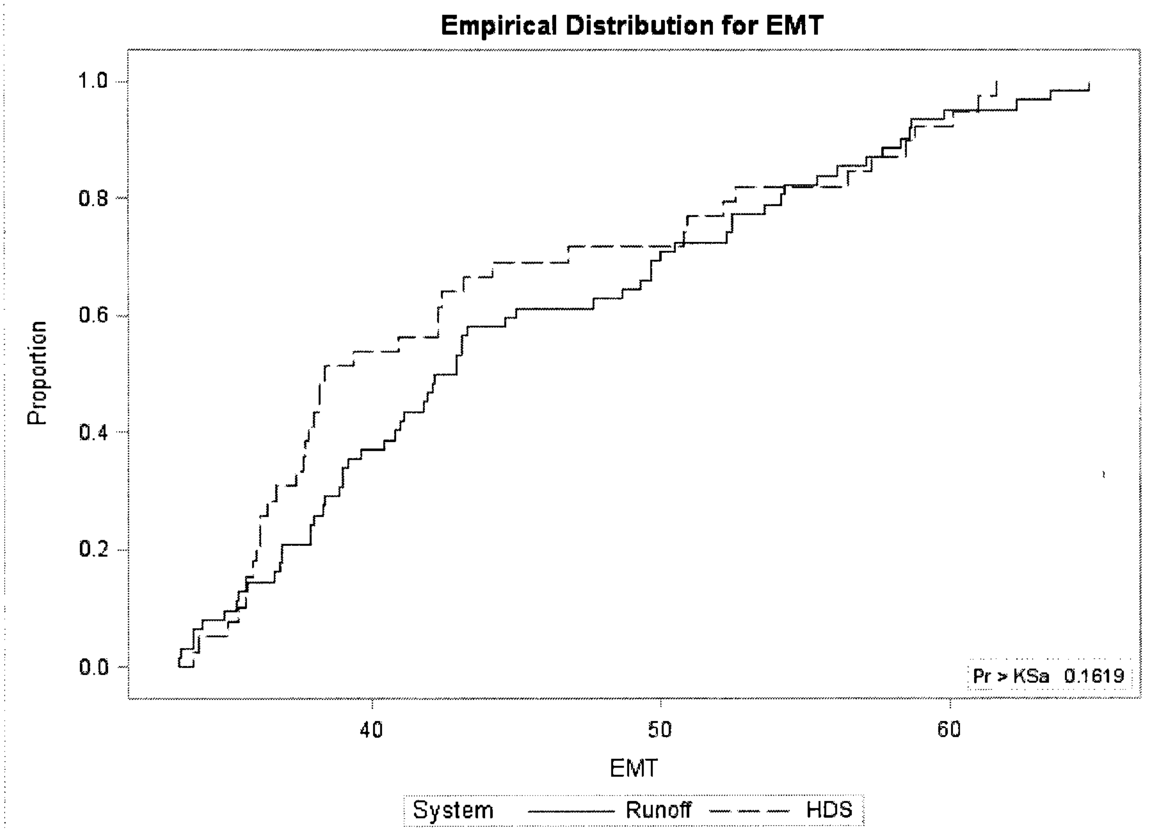
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.25806	-0.6966
HDS	39	0.48718	0.87833
Total	101	0.34653	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.111548	D	0.229115
KSa	1.121040	Pr > KSa	0.1619

Empirical Distribution Function Plot for EMT Classified by System



ADS Infiltration System (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

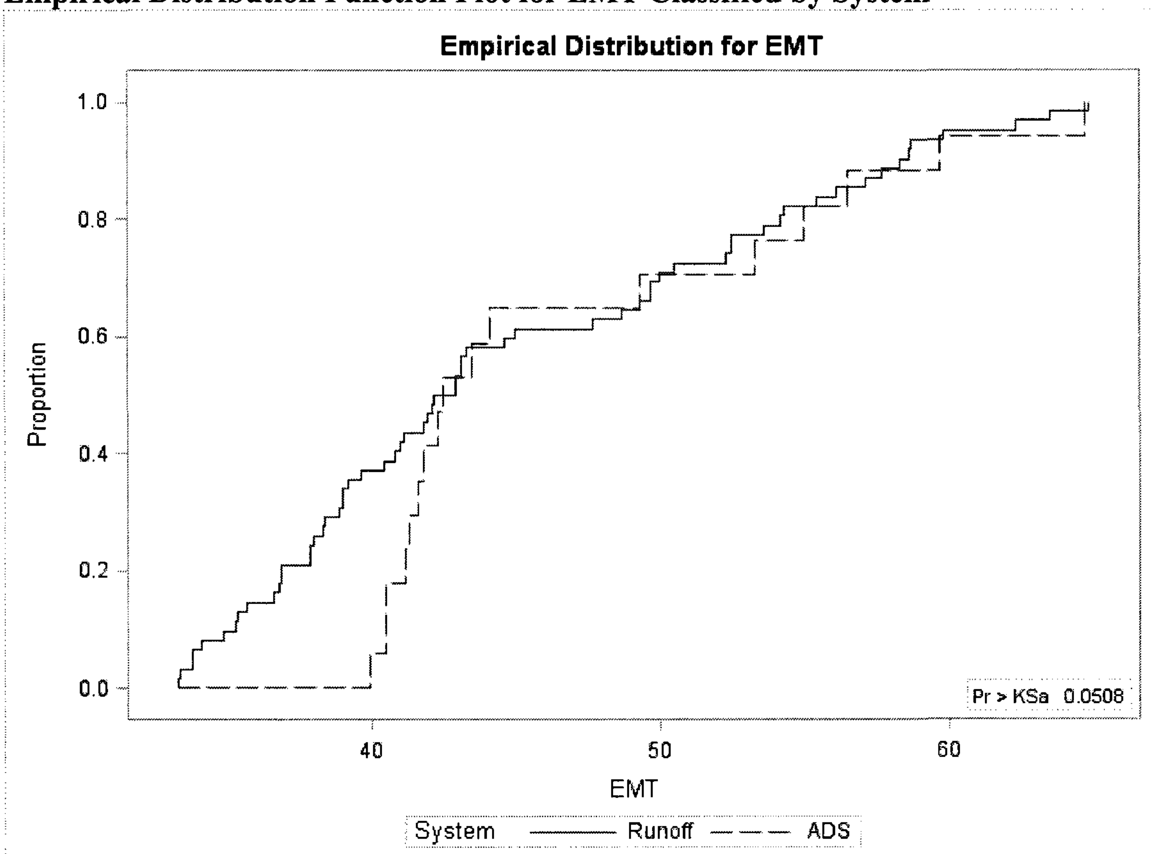
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.37097	0.62857
ADS	17	0	-1.2004
Total	79	0.29114	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.152451	D	0.370968
KSa	1.355011	Pr > KSa	0.0508

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row (Winter)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

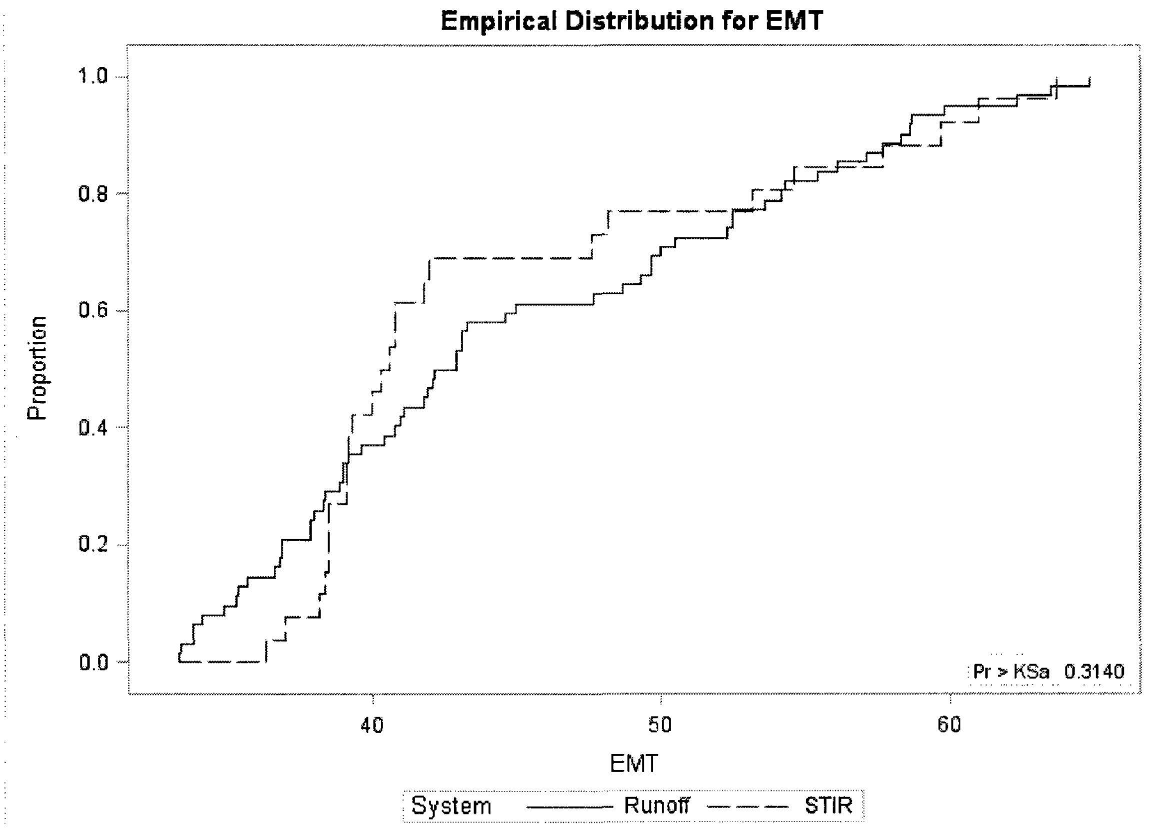
System	N	EDF at Maximum	Deviation from Mean at Maximum
Runoff	62	0.46774	-0.5224
STIR	26	0.69231	0.80675
Total	88	0.53409	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.102457	D	0.224566
KSa	0.961136	Pr > KSa	0.3140

Empirical Distribution Function Plot for EMT Classified by System



College Brook (d/s) vs. Wednesday Hill Brook (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

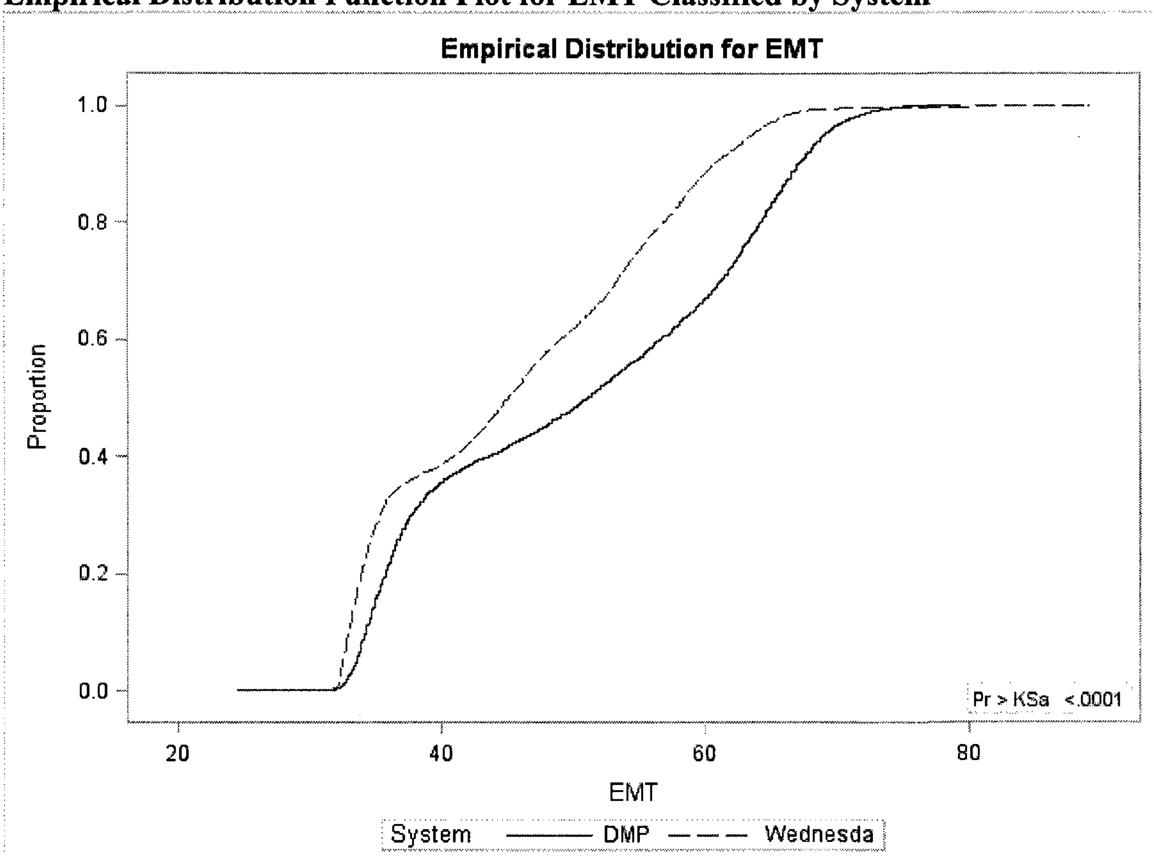
System	N	EDF at Maximum	Deviation from Mean at Maximum
DMP	86056	0.6764	-21.733
Wednesday	44539	0.89362	30.2088
Total	130595	0.75048	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.102978	D	0.217225
KSa	37.214008	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



College Brook (d/s) vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

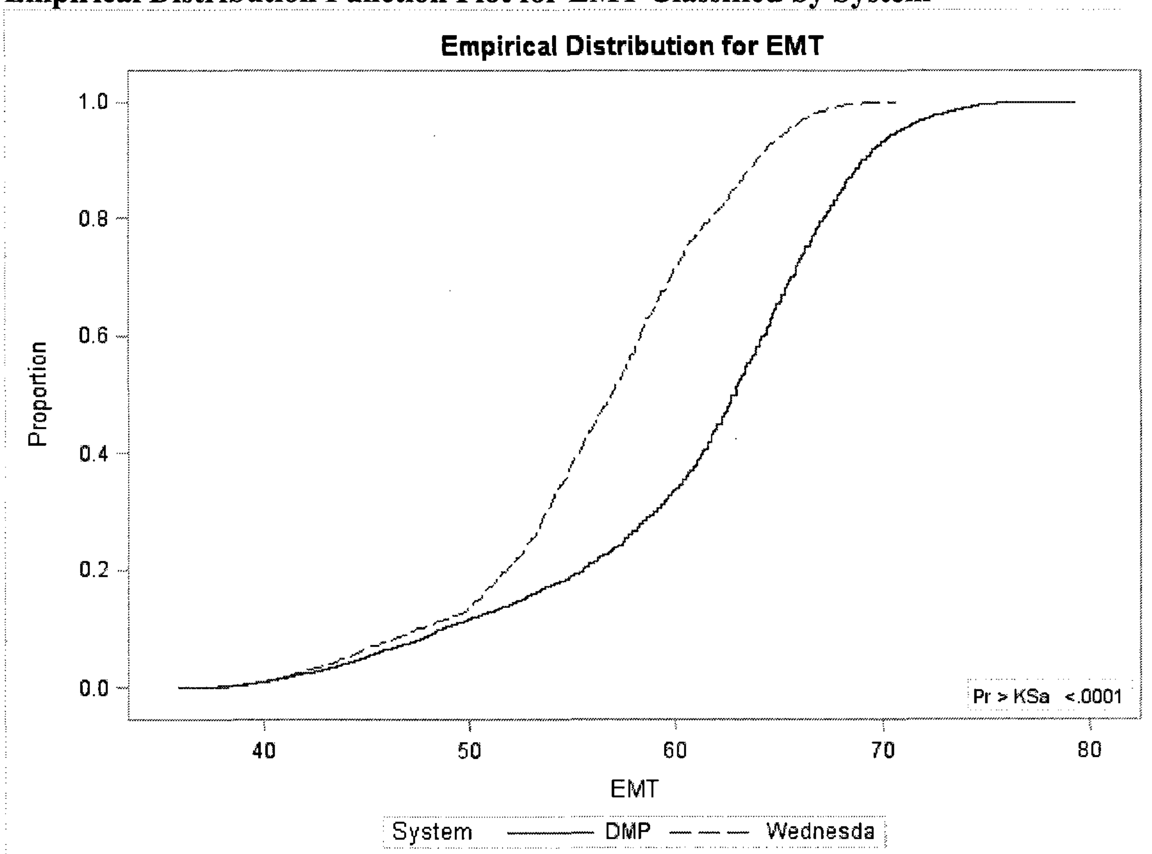
System	N	EDF at Maximum	Deviation from Mean at Maximum
DMP	42900	0.36981	-23.138
Wednesday	17068	0.7623	36.6824
Total	59968	0.48152	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.177104	D	0.392490
KSa	43.369958	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs College Brook (d/s) Annual

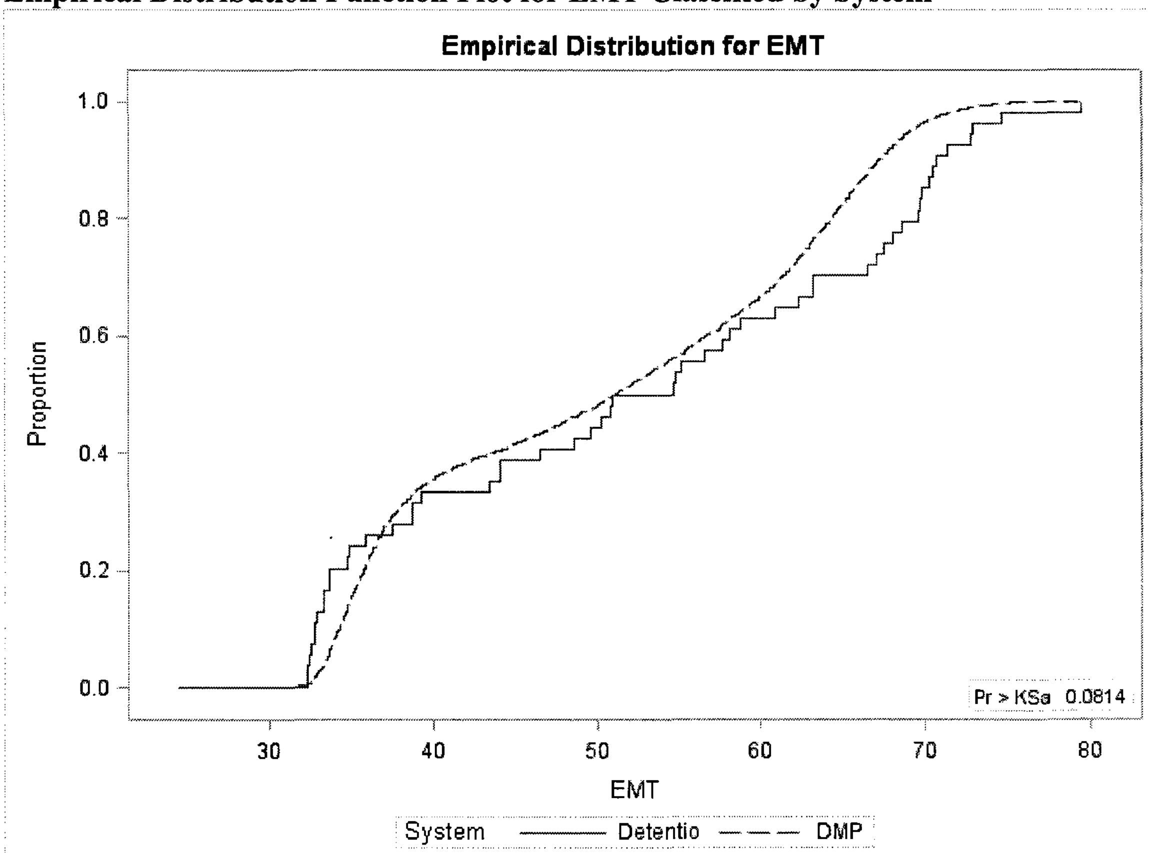
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	54	0.7037	-1.2648
DMP	86056	0.87593	0.03168
Total	86110	0.87582	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.004312	D	0.172226
KSa	1.265200	Pr > KSa	0.0814

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. College Brook (d/s) (Summer)

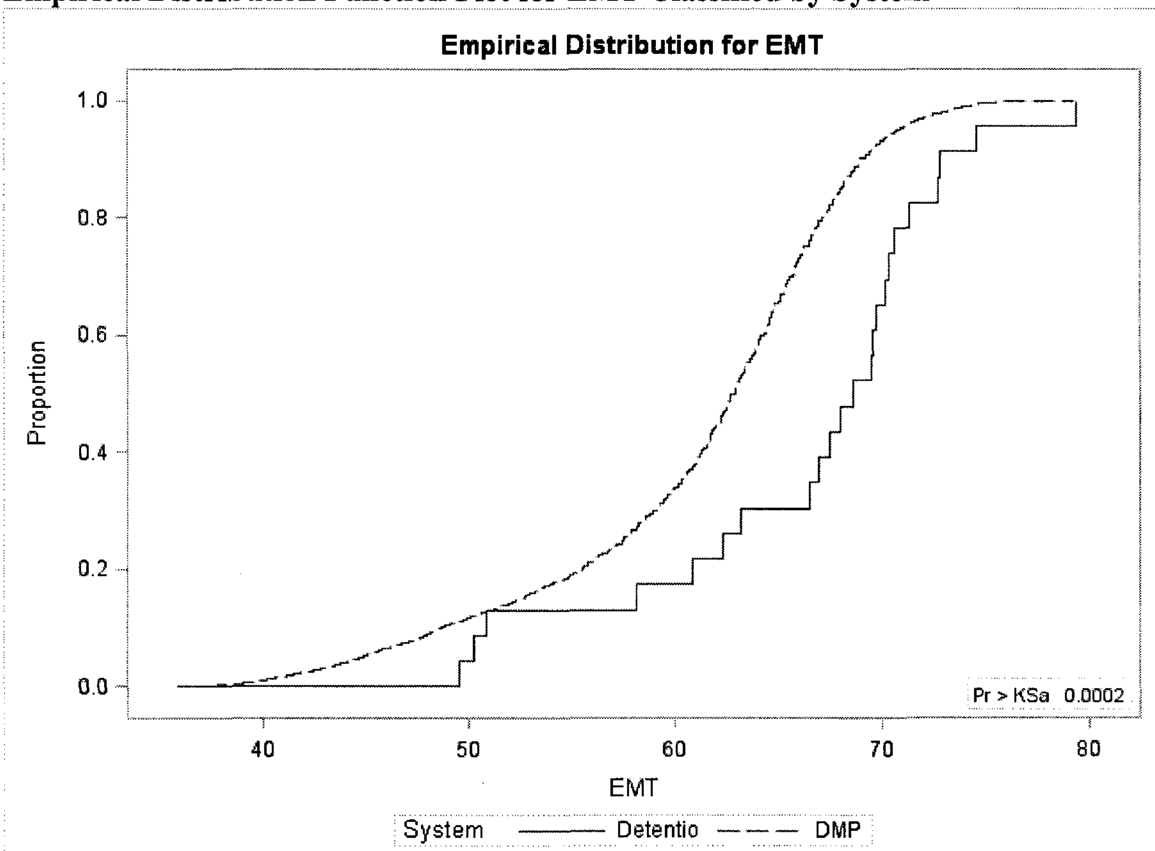
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	23	0.30435	-2.1416
DMP	42900	0.75114	0.04959
Total	42923	0.7509	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.010340	D	0.446794
KSa	2.142176	Pr > KSa	0.0002

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. Wednesday Hill Brook (Annual)

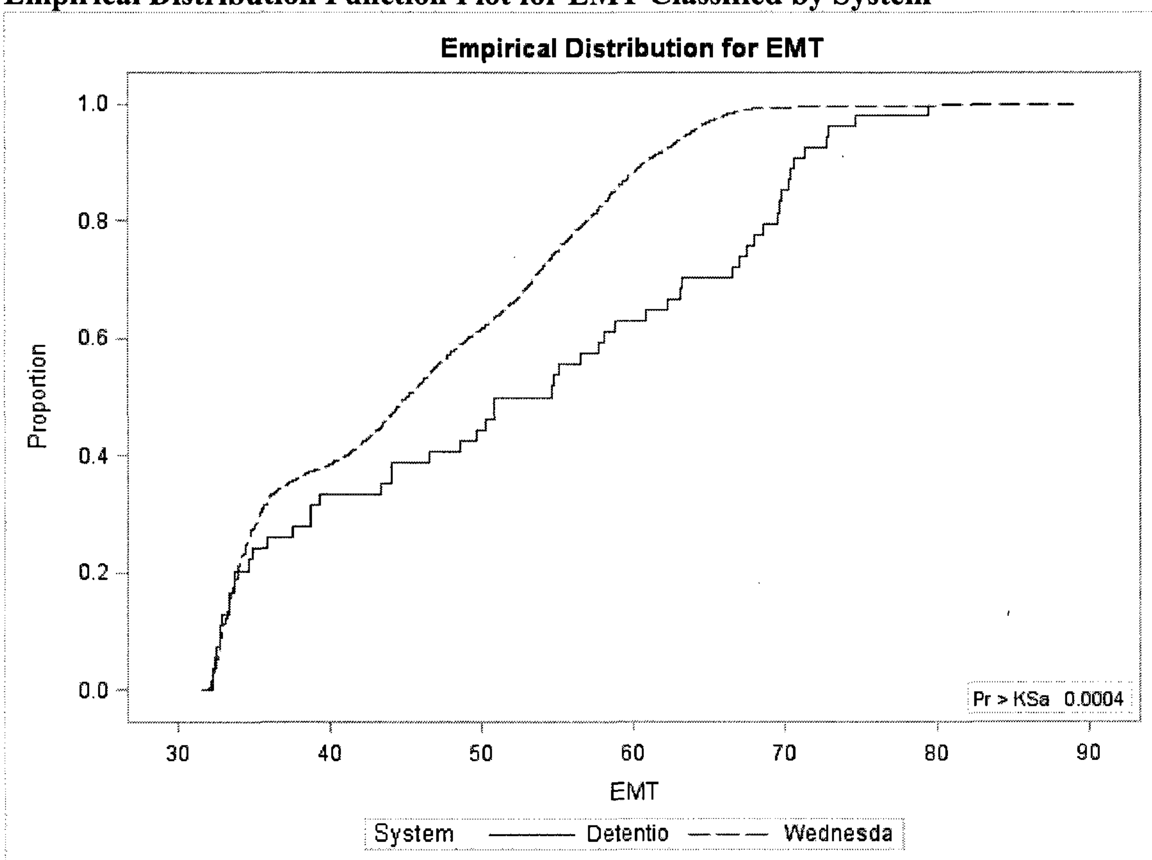
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	54	0.7037	-2.0628
Wednesday	44539	0.98475	0.07183
Total	44593	0.98441	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.009774	D	0.281051
KSa	2.064045	Pr > KSa	0.0004

Empirical Distribution Function Plot for EMT Classified by System



Detention Pond vs. Wednesday Hill Brook (Summer)

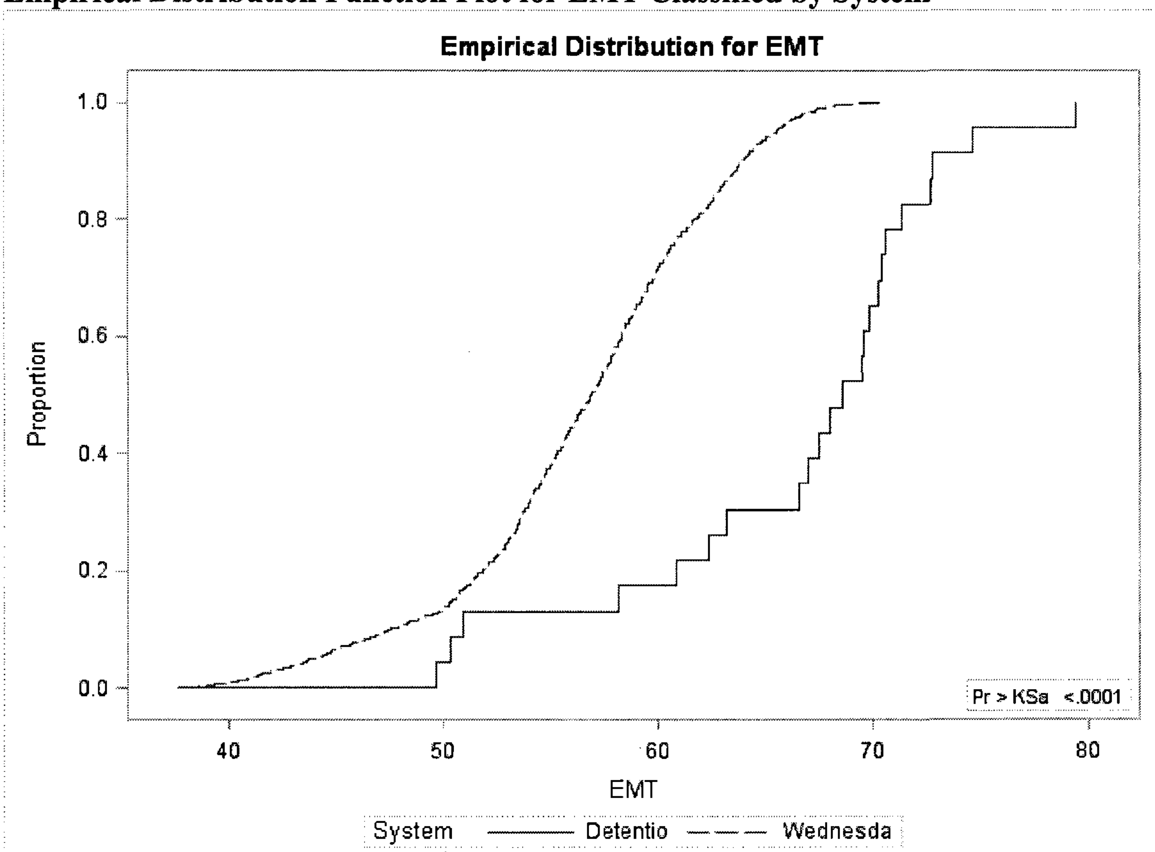
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Detention	23	0.30435	-3.2122
Wednesday	17068	0.97504	0.11792
Total	17091	0.97414	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.024587	D	0.670693
KSa	3.214366	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. College Brook (d/s) (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

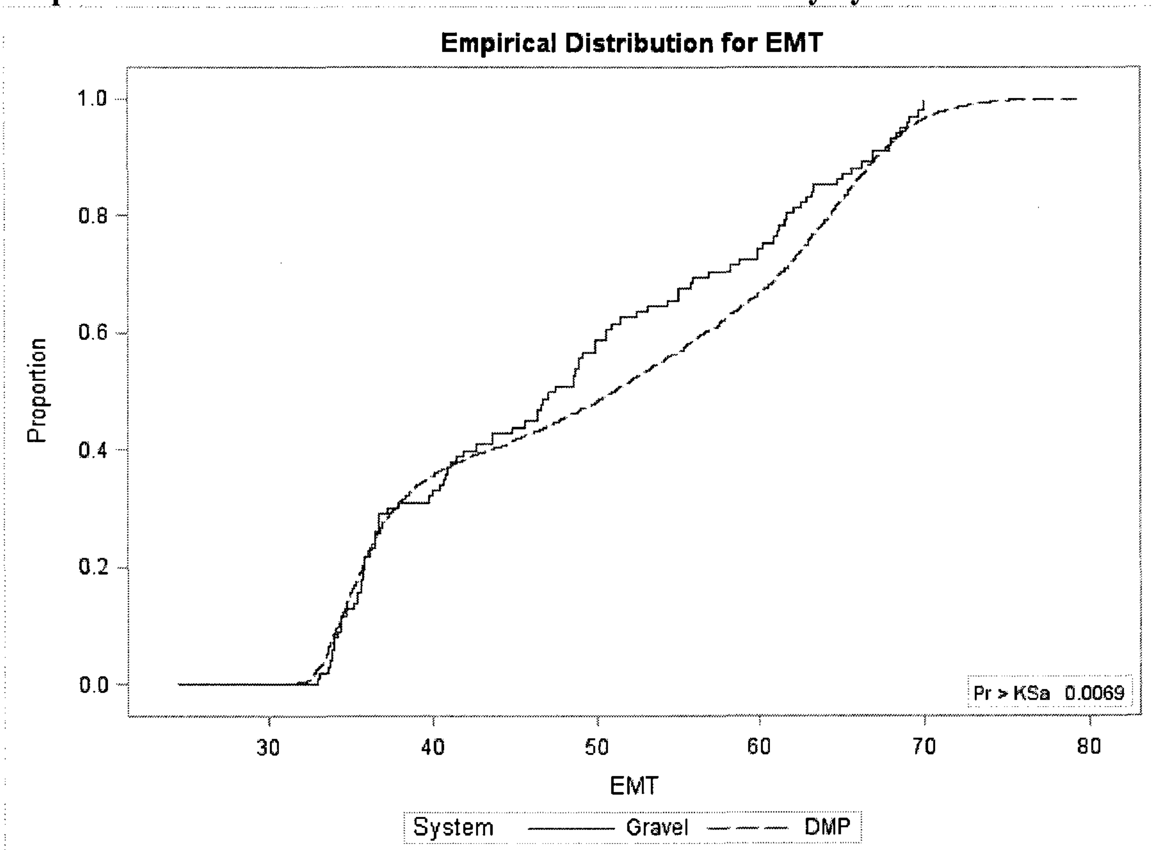
System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	203	0.61576	1.68204
DMP	172111	0.49757	-0.0578
Total	172314	0.49771	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.004054	D	0.118195
KSa	1.683029	Pr > KSa	0.0069

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. College Brook (d/s) (Summer)

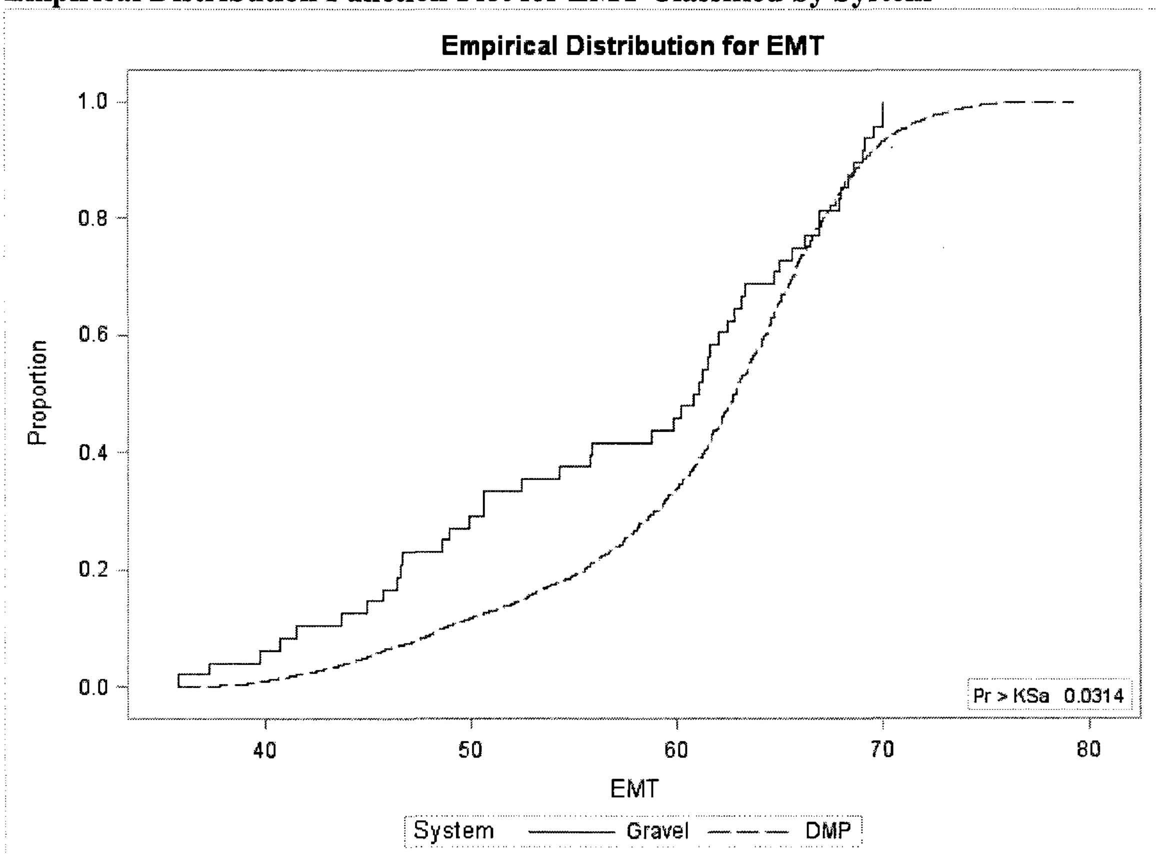
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	48	0.33333	1.44055
DMP	42900	0.12517	-0.0482
Total	42948	0.12541	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.006955	D	0.208159
KSa	1.441358	Pr > KSa	0.0314

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. Wednesday Hill Brook (Annual)

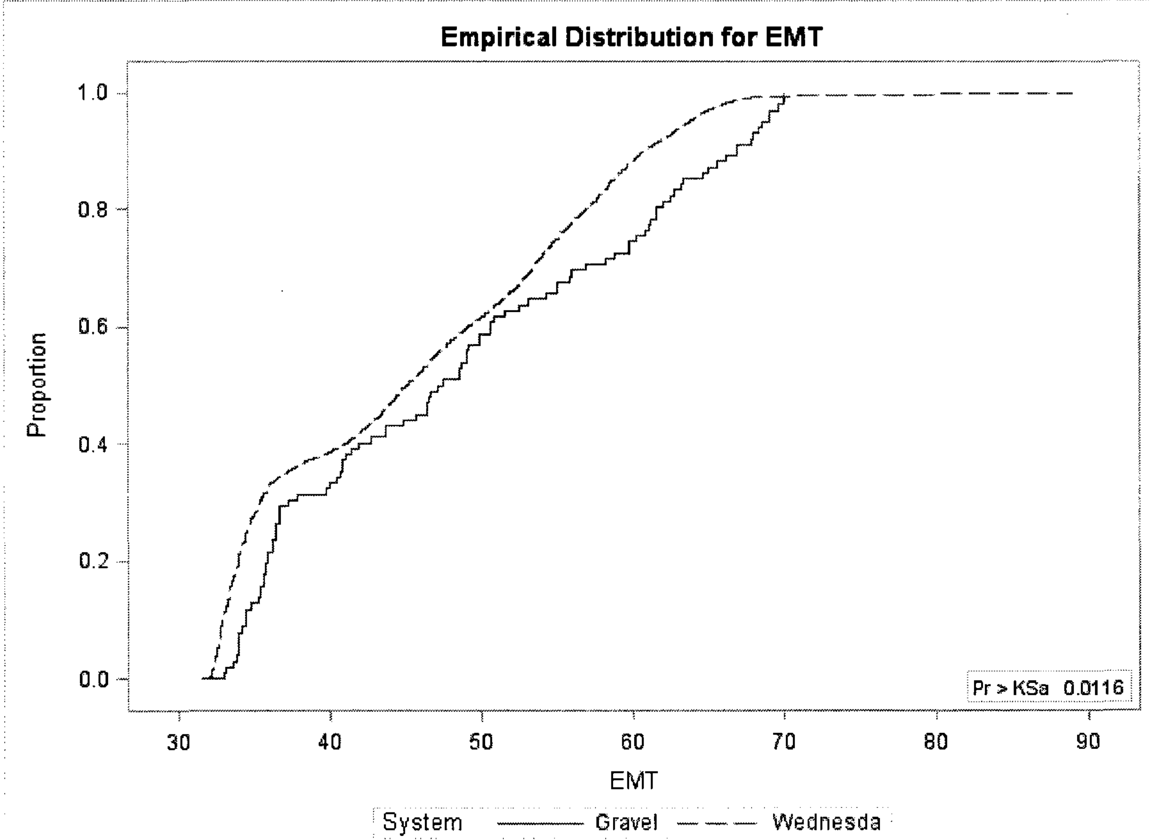
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	102	0.13725	-1.6029
Wednesday	44539	0.29632	0.07671
Total	44641	0.29596	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.007595	D	0.159070
KSa	1.604688	Pr > KSa	0.0116

Empirical Distribution Function Plot for EMT Classified by System



Gravel Wetland vs. Wednesday Hill Brook (Summer)

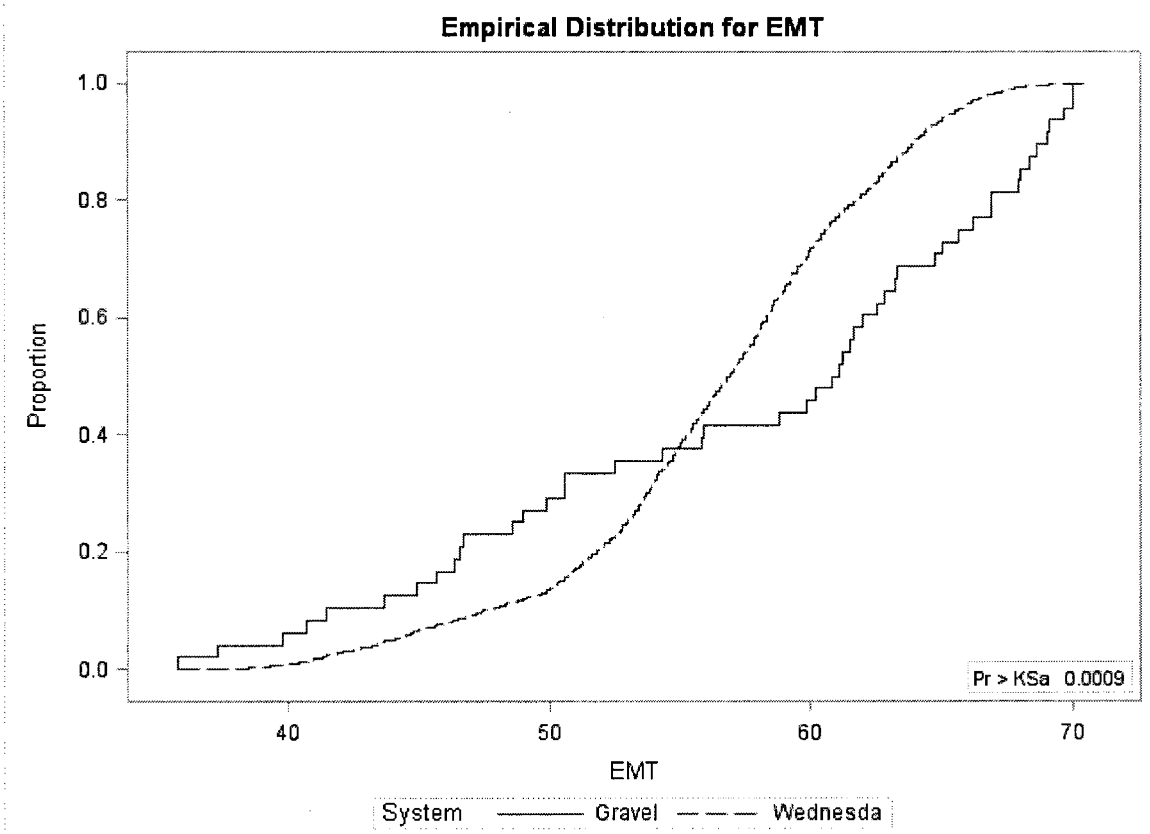
Kolmogorov-Smirnov Test
Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

System	N	EDF at Maximum	Deviation from Mean at Maximum
Gravel	48	0.47917	-1.9561
Wednesday	17068	0.7623	0.10374
Total	17116	0.76151	.

Kolmogorov-Smirnov Two-Sample Statistics
Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.014973	D	0.283137
KSa	1.958879	Pr > KSa	0.0009

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. College Brook (d/s) (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

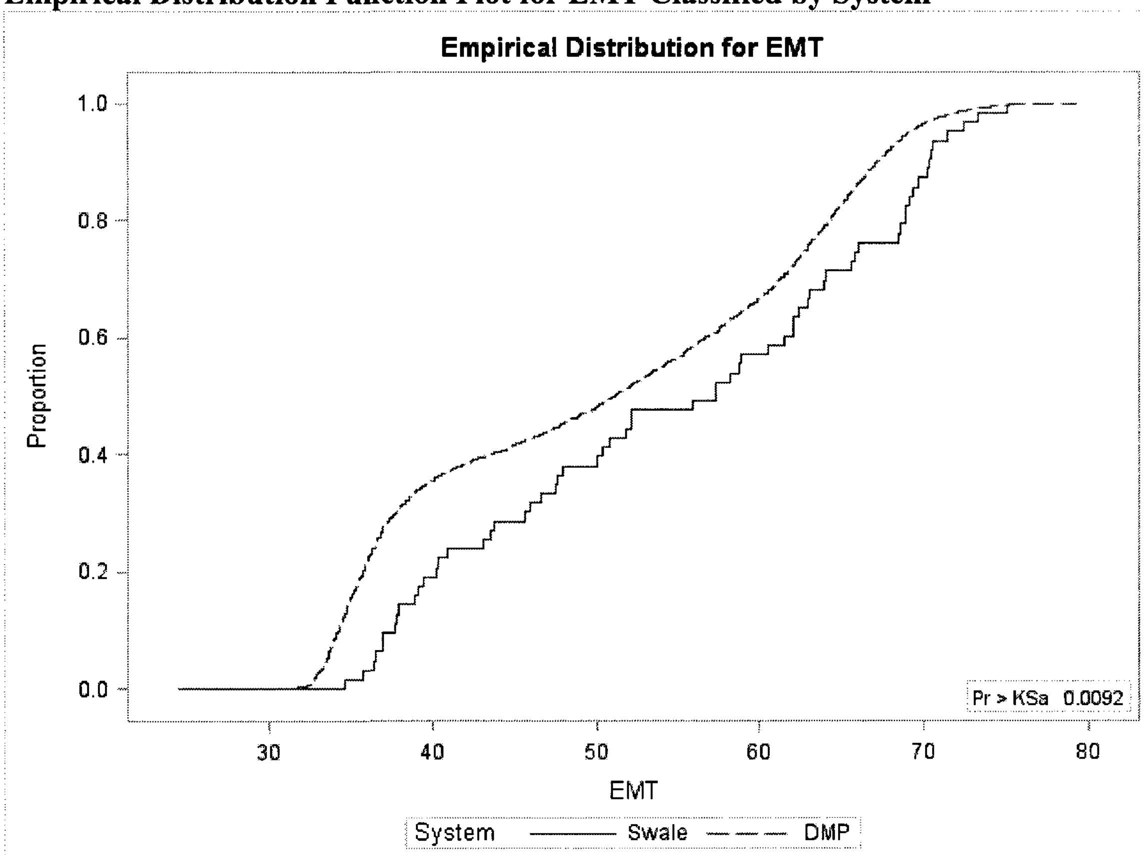
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	63	0.03175	-1.6403
DMP	86056	0.23855	0.04438
Total	86119	0.2384	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.005592	D	0.206808
KSa	1.640887	Pr > KSa	0.0092

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. College Brook (d/s) (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

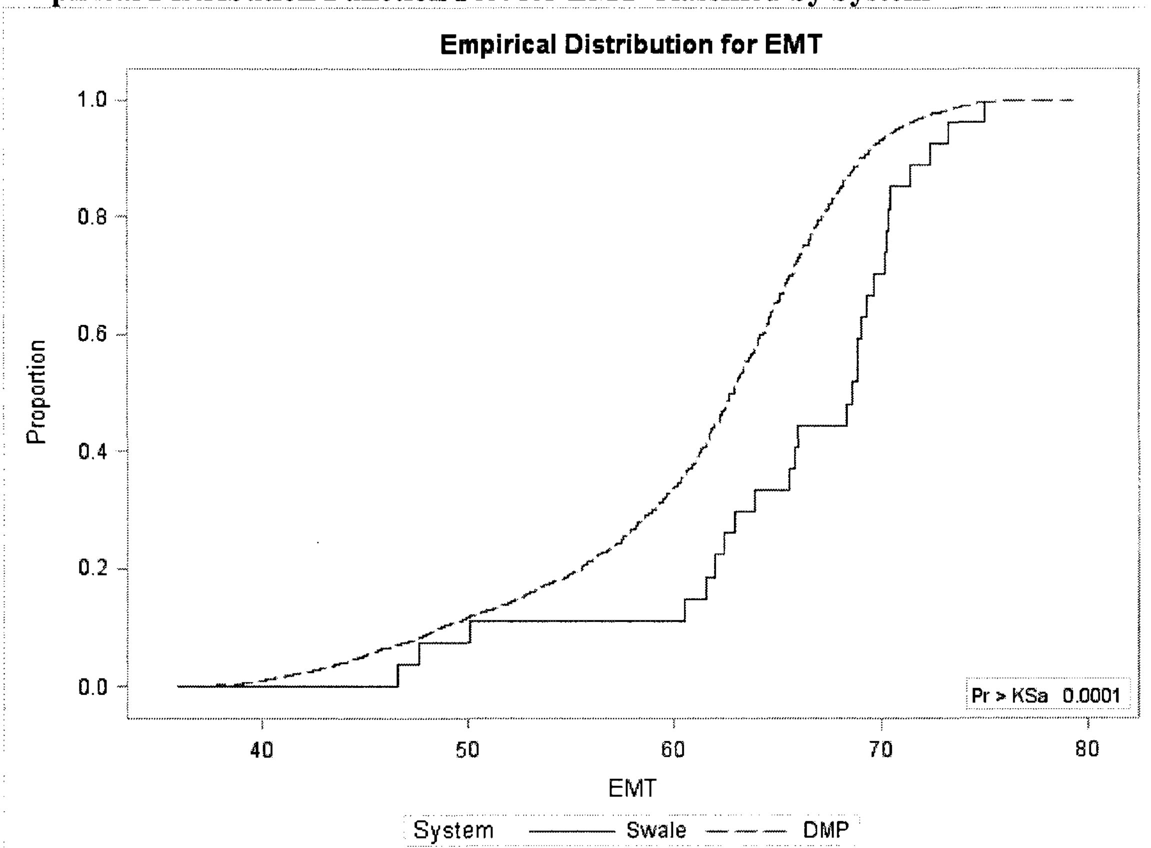
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	27	0.44444	-2.2047
DMP	42900	0.869	0.05531
Total	42927	0.86873	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.010644	D	0.424553
KSa	2.205349	Pr > KSa	0.0001

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. Wednesday Hill Brook (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

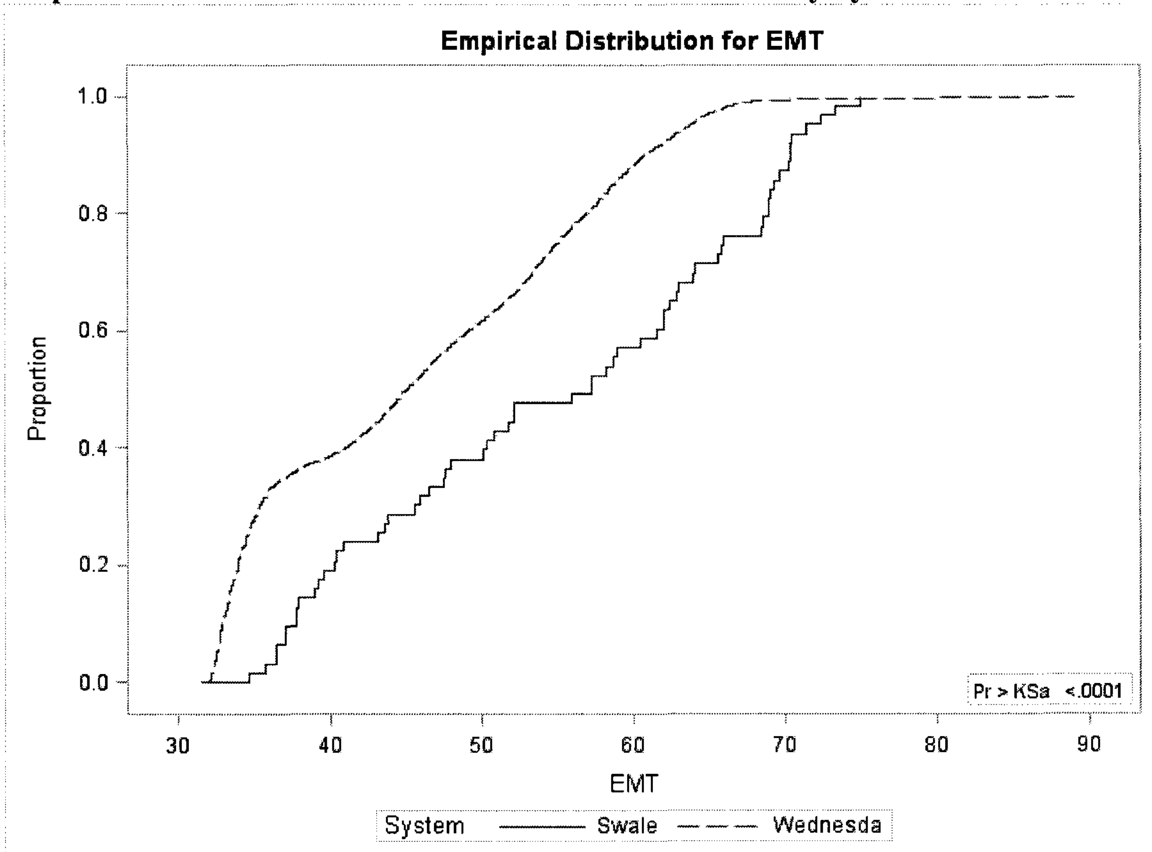
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	63	0.5873	-2.5809
Wednesday	44538	0.91293	0.09707
Total	44601	0.91247	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.012230	D	0.325627
KSa	2.582756	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



Vegetated Swale vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

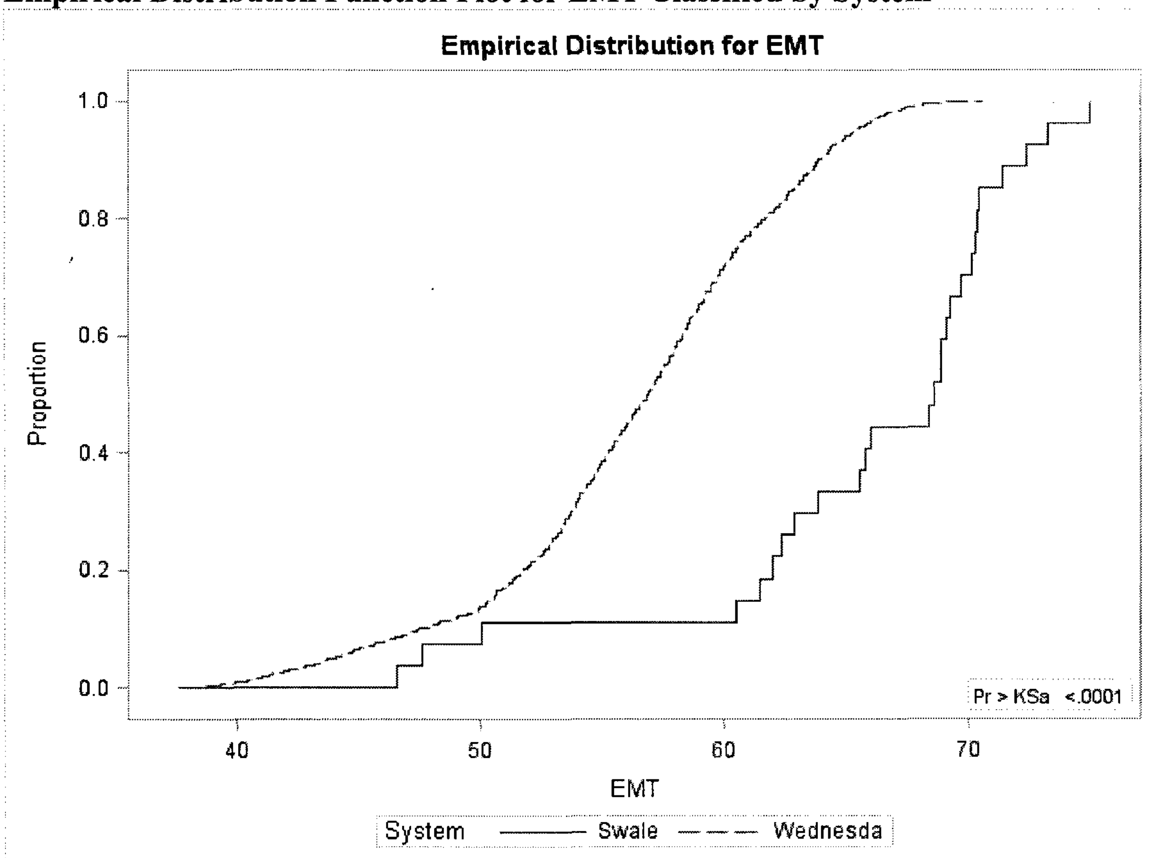
System	N	EDF at Maximum	Deviation from Mean at Maximum
Swale	27	0.14815	-3.3409
Wednesday	17068	0.79213	0.13288
Total	17095	0.79111	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.025573	D	0.643977
KSa	3.343562	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. College Brook (d/s) (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

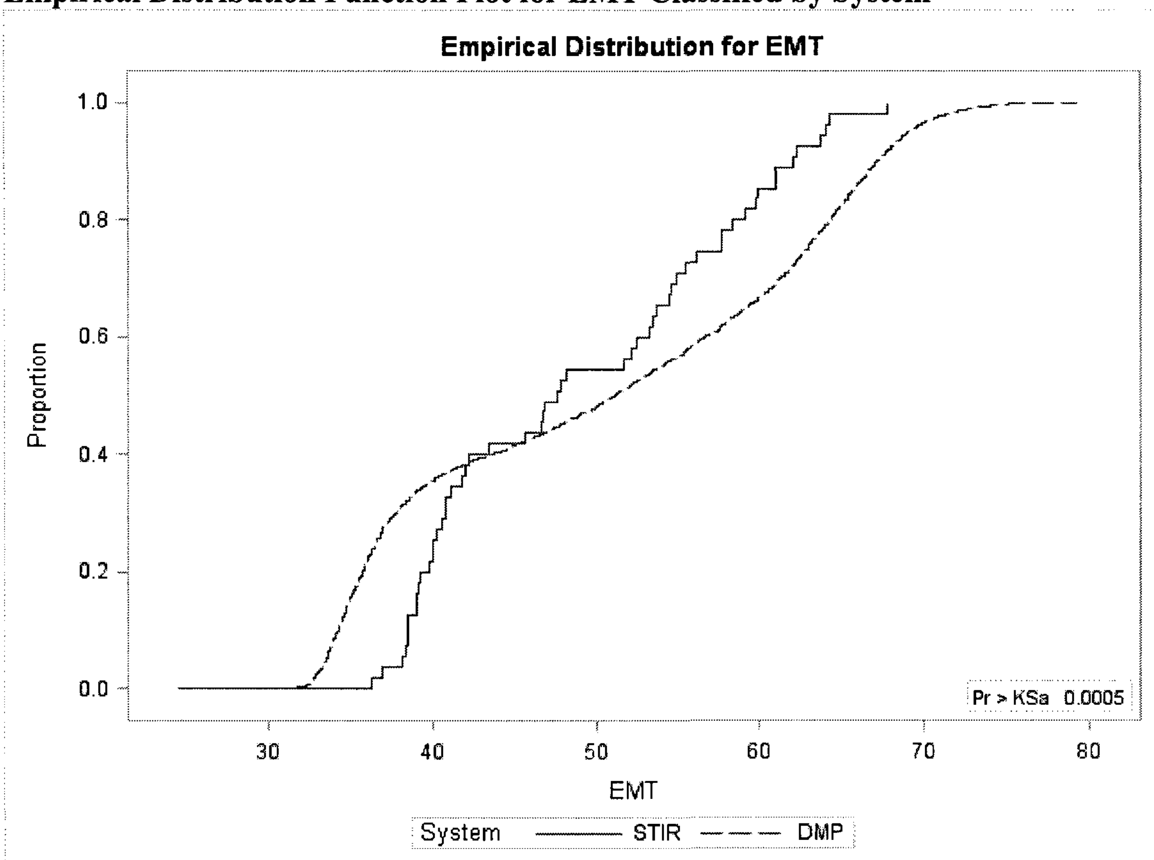
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	55	0.03636	-2.0357
DMP	86056	0.31103	0.05146
Total	86111	0.31085	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.006939	D	0.274666
KSa	2.036330	Pr > KSa	0.0005

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. College Brook (d/s) (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

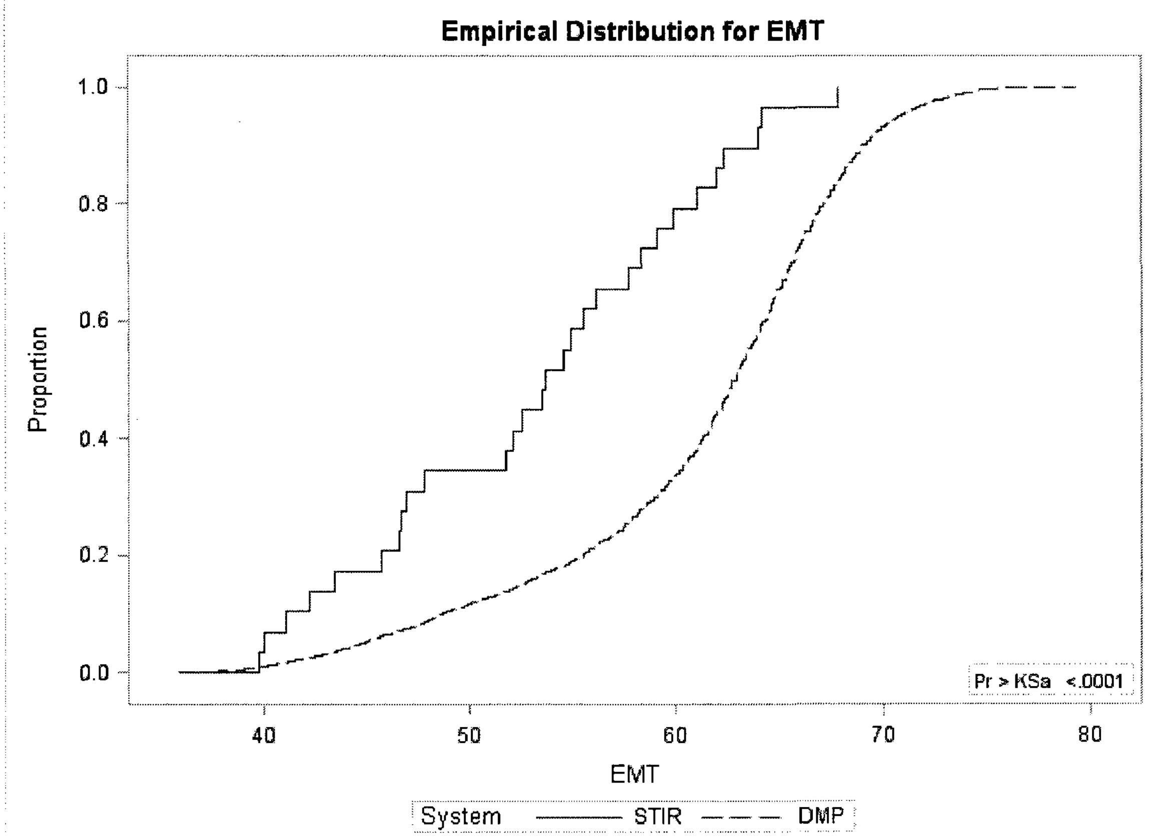
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	29	0.7931	2.45256
DMP	42900	0.33737	-0.0638
Total	42929	0.33767	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.011841	D	0.455737
KSa	2.453392	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. Wednesday Hill Brook (Annual)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

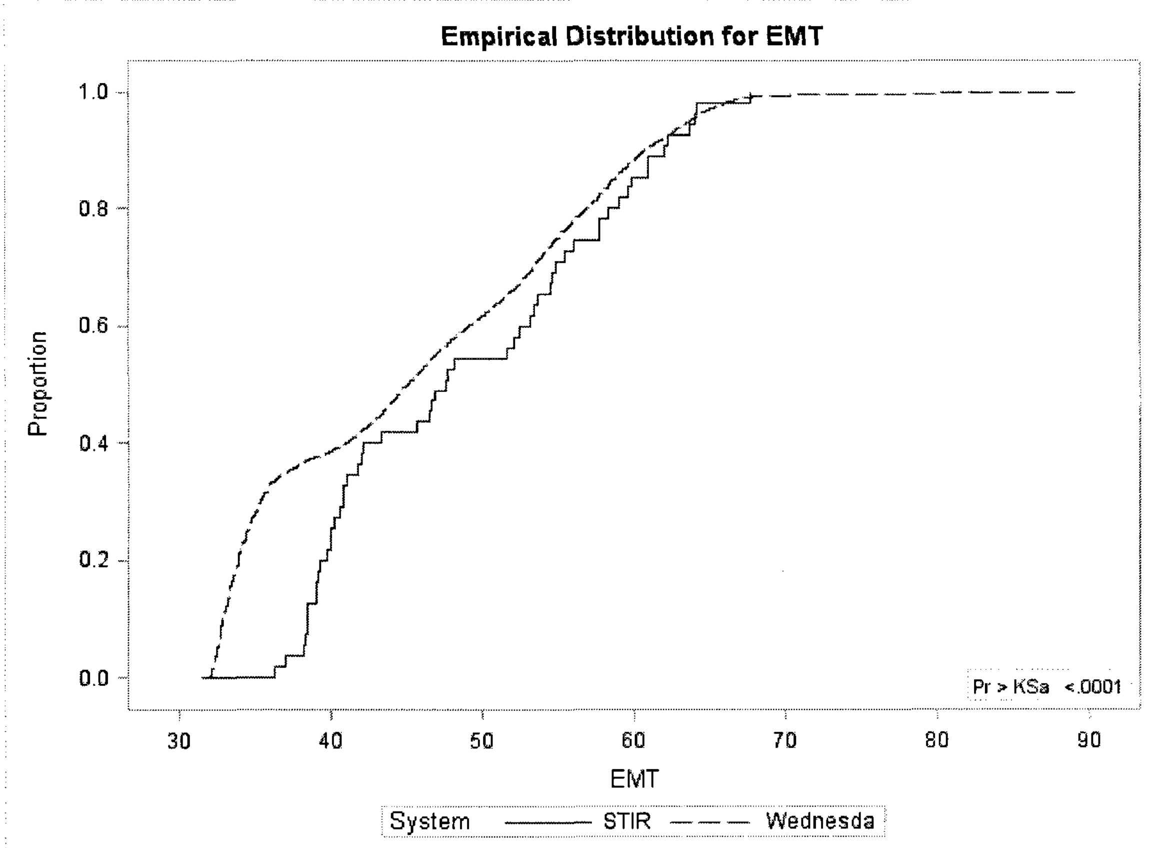
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	55	0	-2.4806
Wednesday	44539	0.3349	0.08717
Total	44594	0.33448	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.011754	D	0.334898
KSa	2.482134	Pr > KSa	<.0001

Empirical Distribution Function Plot for EMT Classified by System



StormTech Isolator Row vs. Wednesday Hill Brook (Summer)

Kolmogorov-Smirnov Test

Kolmogorov-Smirnov Test for Variable EMT Classified by Variable System

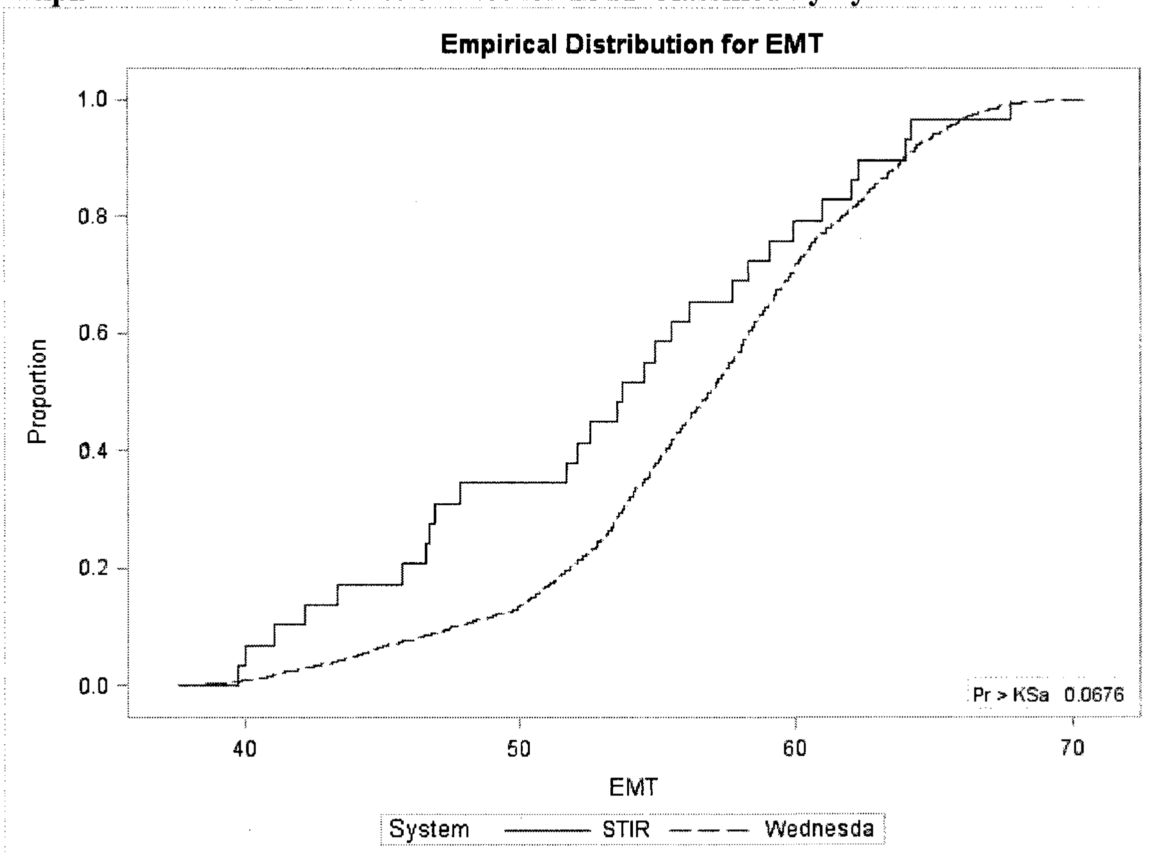
System	N	EDF at Maximum	Deviation from Mean at Maximum
STIR	29	0.34483	1.30039
Wednesday	17068	0.10294	-0.0536
Total	17097	0.10335	.

Kolmogorov-Smirnov Two-Sample Statistics

Kolmogorov-Smirnov 2-Sample Test (Asymptotic)

KS	0.009954	D	0.241886
KSa	1.301493	Pr > KSa	0.0676

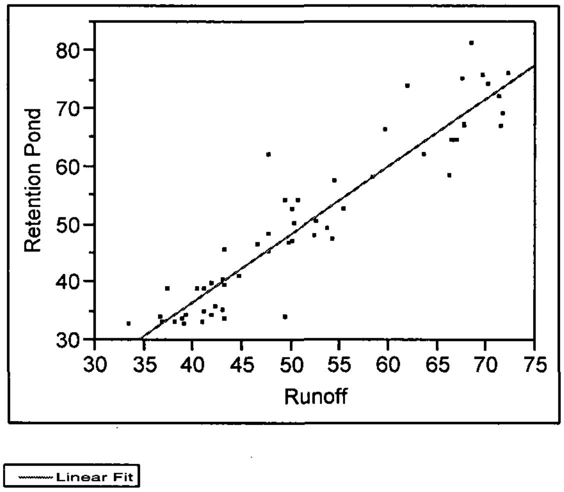
Empirical Distribution Function Plot for EMT Classified by System



APPENDIX H

SYSTEM TREATMENT STATISTICS
(ANNUAL, SUMMER, WINTER)

Bivariate Fit of Retention Pond By Runoff (Annual)



Linear Fit: Retention Pond = -10.23365 + 1.1738466*Runoff

Summary of Fit	
RSquare	0.878613
RSquare Adj	0.876365
Root Mean Square Error	5.135817
Mean of Response	50.88393
Observations (or Sum Wgts)	56

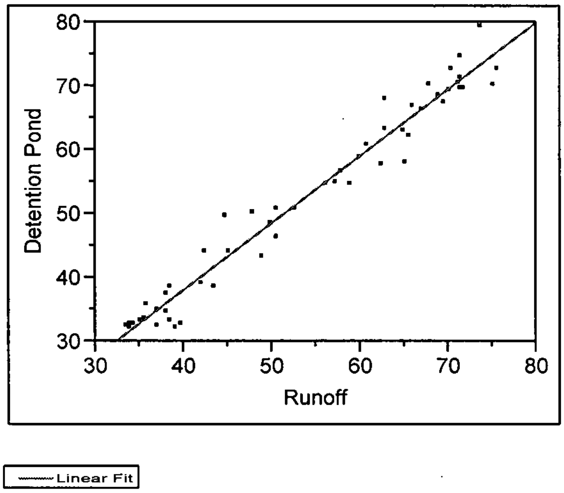
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	10309.518	10309.5	390.8582
Error	54	1424.338	26.4	**Prob > F**
C. Total	55	11733.856		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-10.23365	3.166674	-3.23	0.0021*
Slope	1.1738466	0.059375	19.77	<.0001*

Bivariate Fit of Detention Pond By Runoff (Annual)



Linear Fit: Detention Pond = -3.631256 + 1.044837*Runoff

Summary of Fit	
RSquare	0.966596
RSquare Adj	0.965953
Root Mean Square Error	2.785725
Mean of Response	52.29074
Observations (or Sum Wgts)	54

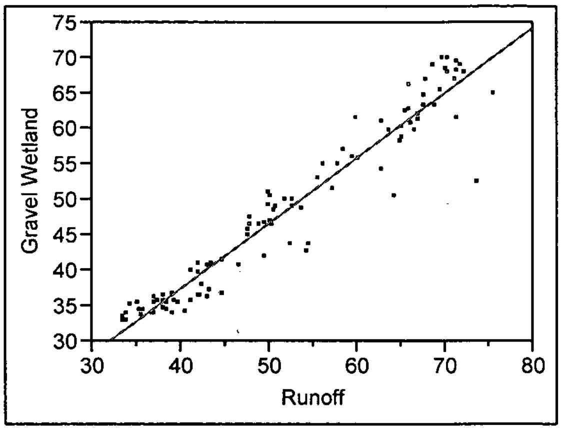
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	11676.692	11676.7	1504.677
Error	52	403.534	7.8	**Prob > F**
C. Total	53	12080.225		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-3.631256	1.490662	-2.44	0.0183*
Slope	1.044837	0.026936	38.79	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Annual)



Linear Fit: Gravel Wetland = 0.8089851 + 0.9184349*Runoff

Summary of Fit	
RSquare	0.930068
RSquare Adj	0.929368
Root Mean Square Error	3.202597
Mean of Response	48.67745
Observations (or Sum Wgts)	102

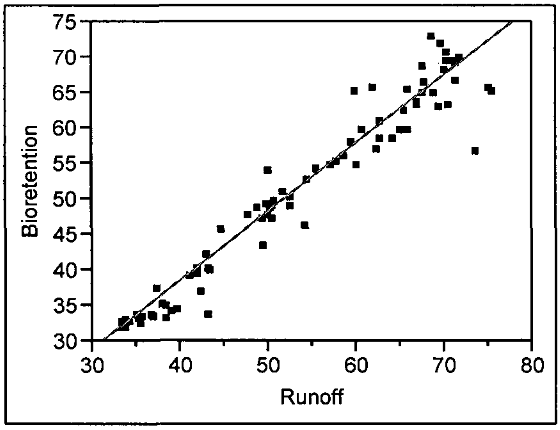
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	13640.875	13640.9	1329.957
Error	100	1025.663	10.3	**Prob > F**
C. Total	101	14666.538		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.8089851	1.350356	0.60	0.5505
Slope	0.9184349	0.025184	36.47	<.0001*

Bivariate Fit of Bioretention By Runoff (Annual)



Linear Fit: Bioretention = 0.1509641 + 0.9629206*Runoff

Summary of Fit	
RSquare	0.940743
RSquare Adj	0.940012
Root Mean Square Error	3.198489
Mean of Response	51.94217
Observations (or Sum Wgts)	83

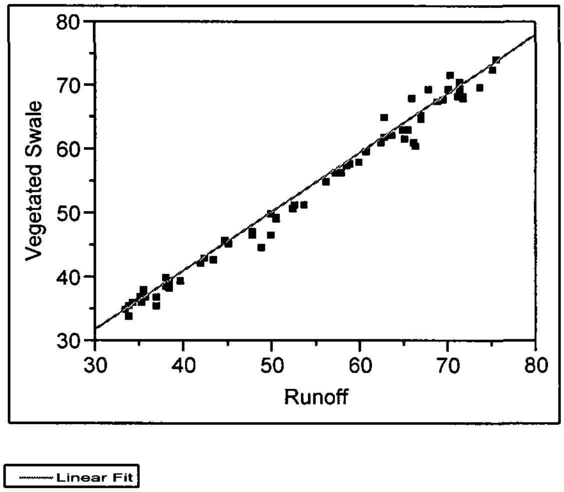
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	13155.566	13155.6	1285.938
Error	81	828.657	10.2	**Prob > F**
C. Total	82	13984.222		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.1509641	1.486321	0.10	0.9193
Slope	0.9629206	0.026852	35.86	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Annual)



Linear Fit: Vegetated Swale = 4.3812395 + 0.9210901*Runoff

Summary of Fit	
RSquare	0.985943
RSquare Adj	0.985712
Root Mean Square Error	1.503185
Mean of Response	54.78095
Observations (or Sum Wgts)	63

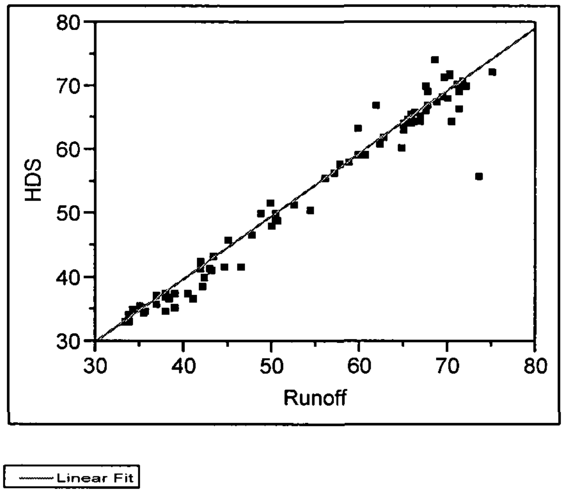
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	9667.4037	9667.40	4278.436
Error	61	137.8334	2.26	**Prob > F**
C. Total	62	9805.2371		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.3812395	0.793455	5.52	<.0001*
Slope	0.9210901	0.014082	65.41	<.0001*

Bivariate Fit of HDS By Runoff (Annual)



Linear Fit: HDS = 0.2914269 + 0.9874263*Runoff

Summary of Fit	
RSquare	0.960432
RSquare Adj	0.959938
Root Mean Square Error	2.731432
Mean of Response	54.11098
Observations (or Sum Wgts)	82

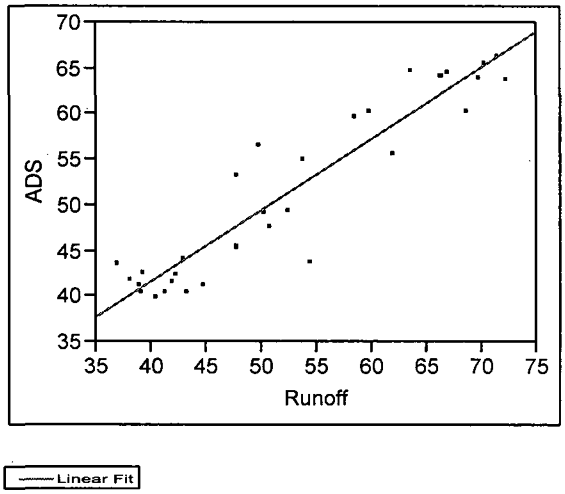
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	14487.642	14487.6	1941.855
Error	80	596.858	7.5	**Prob > F**
C. Total	81	15084.500		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2914269	1.258023	0.23	0.8174
Slope	0.9874263	0.022408	44.07	<.0001*

Bivariate Fit of ADS By Runoff (Annual)



Linear Fit: ADS = 10.119814 + 0.785959*Runoff

Summary of Fit	
RSquare	0.884098
RSquare Adj	0.880359
Root Mean Square Error	3.355553
Mean of Response	51.46364
Observations (or Sum Wgts)	33

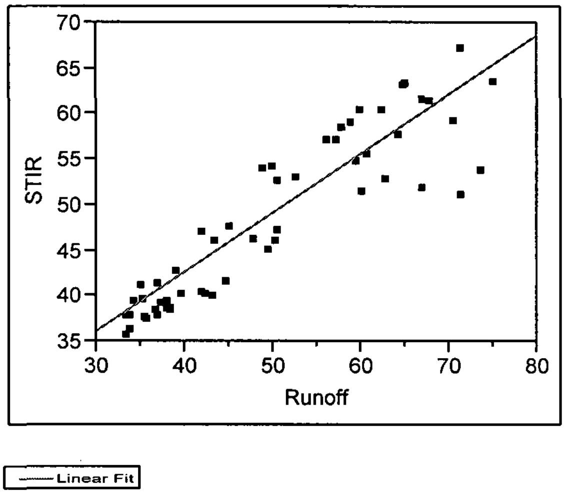
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2662.5646	2662.56	236.4678
Error	31	349.0518	11.26	**Prob > F**
C. Total	32	3011.6164		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	10.119814	2.751313	3.68	0.0009*
Slope	0.785959	0.051111	15.38	<.0001*

Bivariate Fit of STIR By Runoff (Annual)



Linear Fit: STIR = 16.622529 + 0.6496884*Runoff

Summary of Fit	
RSquare	0.832033
RSquare Adj	0.828864
Root Mean Square Error	3.801779
Mean of Response	49.00182
Observations (or Sum Wgts)	55

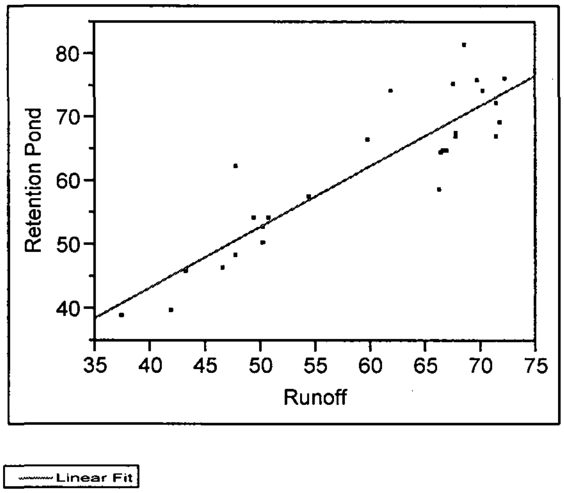
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	3794.6131	3794.61	262.5390
Error	53	766.0367	14.45	**Prob > F**
C. Total	54	4560.6498		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	16.622529	2.063049	8.06	<.0001*
Slope	0.6496884	0.040097	16.20	<.0001*

Bivariate Fit of Retention Pond By Runoff (Summer)



Linear Fit: Retention Pond = 5.1139311 + 0.9543647*Runoff

Summary of Fit	
RSquare	0.804643
RSquare Adj	0.796828
Root Mean Square Error	5.309062
Mean of Response	61.79259
Observations (or Sum Wgts)	27

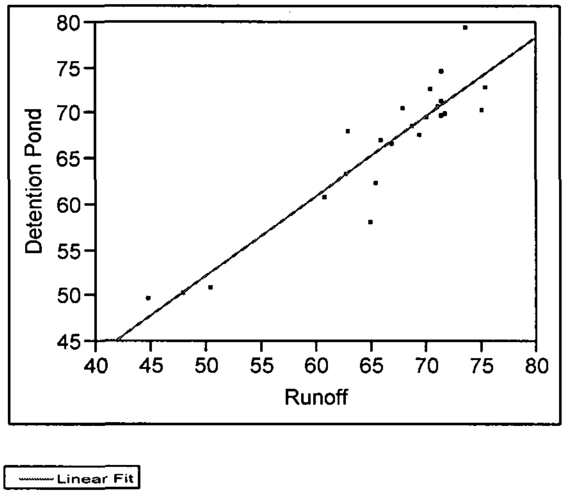
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2902.3451	2902.35	102.9707
Error	25	704.6534	28.19	**Prob > F**
C. Total	26	3606.9985		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	5.1139311	5.678191	0.90	0.3764
Slope	0.9543647	0.09405	10.15	<.0001*

Bivariate Fit of Detention Pond By Runoff (Summer)



Linear Fit: Detention Pond = 8.5917393 + 0.8731744*Runoff

Summary of Fit	
RSquare	0.858822
RSquare Adj	0.852099
Root Mean Square Error	2.998999
Mean of Response	66.24783
Observations (or Sum Wgts)	23

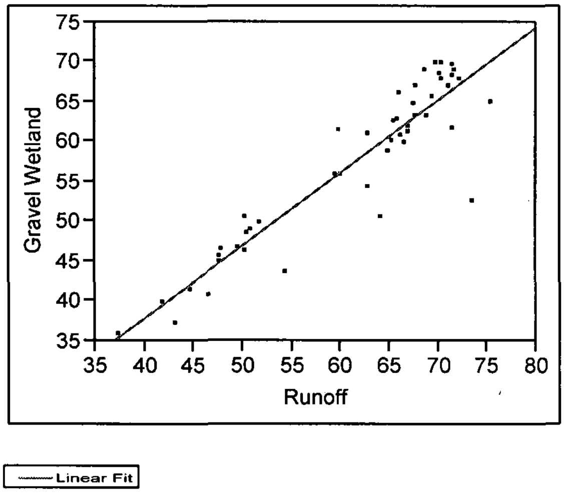
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1148.9635	1148.96	127.7479
Error	21	188.8739	8.99	**Prob > F**
C. Total	22	1337.8374		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.5917393	5.139339	1.67	0.1094
Slope	0.8731744	0.077255	11.30	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Summer)



Linear Fit: Gravel Wetland = 1.5244308 + 0.9101106*Runoff

Summary of Fit	
RSquare	0.85045
RSquare Adj	0.847199
Root Mean Square Error	3.931838
Mean of Response	57.31042
Observations (or Sum Wgts)	48

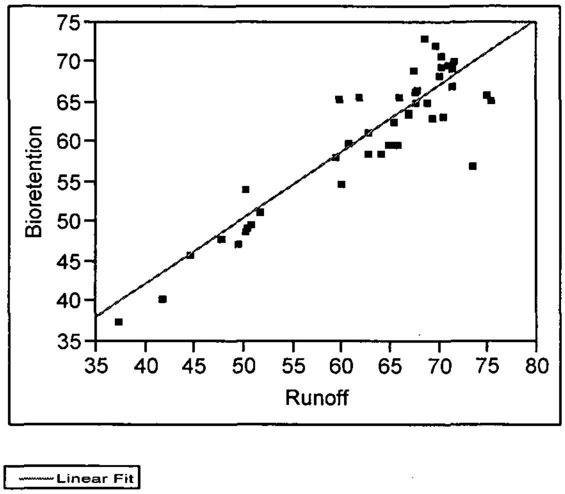
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	4044.0145	4044.01	261.5901
Error	46	711.1303	15.46	**Prob > F**
C. Total	47	4755.1448		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	1.5244308	3.495545	0.44	0.6648
Slope	0.9101106	0.056271	16.17	<.0001*

Bivariate Fit of Bioretention By Runoff (Summer)



Linear Fit: Bioretention = 9.058345 + 0.8309381*Runoff

Summary of Fit	
RSquare	0.820936
RSquare Adj	0.816673
Root Mean Square Error	3.719493
Mean of Response	61.23182
Observations (or Sum Wgts)	44

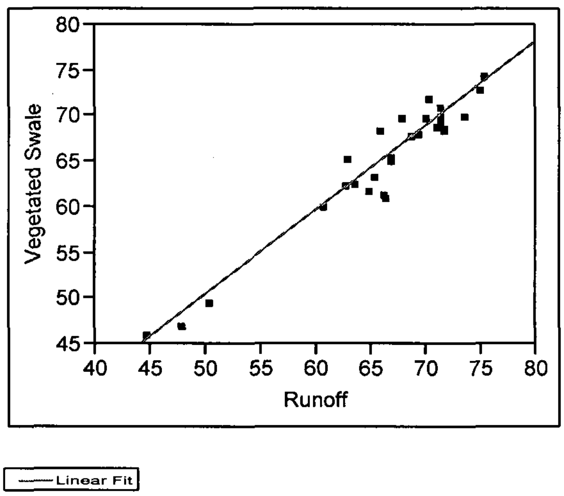
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2663.9012	2663.90	192.5532
Error	42	581.0542	13.83	**Prob > F**
C. Total	43	3244.9555		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.058345	3.801466	2.38	0.0218*
Slope	0.8309381	0.059882	13.88	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Summer)



Linear Fit: Vegetated Swale = 4.4954229 + 0.9219298*Runoff

Summary of Fit	
RSquare	0.93281
RSquare Adj	0.930225
Root Mean Square Error	1.907102
Mean of Response	65.51071
Observations (or Sum Wgts)	28

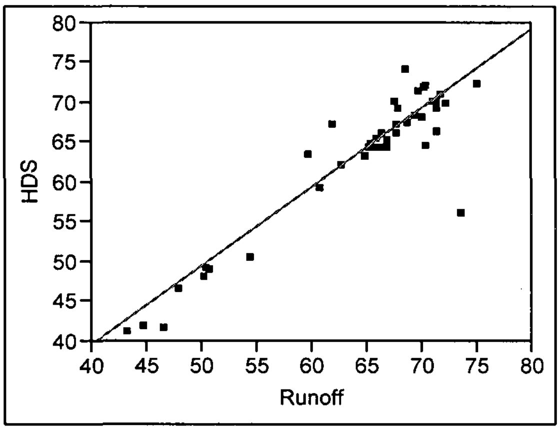
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1312.8238	1312.82	360.9596
Error	26	94.5630	3.64	**Prob > F**
C. Total	27	1407.3868		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.4954229	3.231671	1.39	0.1760
Slope	0.9219298	0.048525	19.00	<.0001*

Bivariate Fit of HDS By Runoff (Summer)



Linear Fit: HDS = -0.051621 + 0.9923862*Runoff

Summary of Fit	
RSquare	0.856128
RSquare Adj	0.852618
Root Mean Square Error	3.486735
Mean of Response	63.84651
Observations (or Sum Wgts)	43

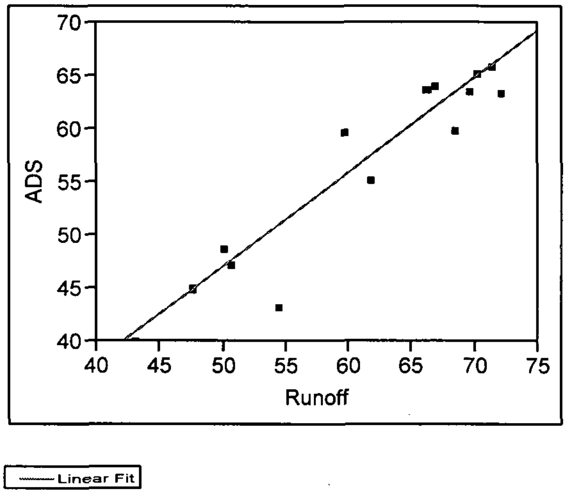
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2966.0769	2966.08	243.9746
Error	41	498.4501	12.16	**Prob > F**
C. Total	42	3464.5270		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.051621	4.125283	-0.01	0.9901
Slope	0.9923862	0.063534	15.62	<.0001*

Bivariate Fit of ADS By Runoff (Summer)



Linear Fit: ADS = 2.4593616 + 0.8915634*Runoff

Summary of Fit	
RSquare	0.906722
RSquare Adj	0.90006
Root Mean Square Error	2.937305
Mean of Response	56.2875
Observations (or Sum Wgts)	16

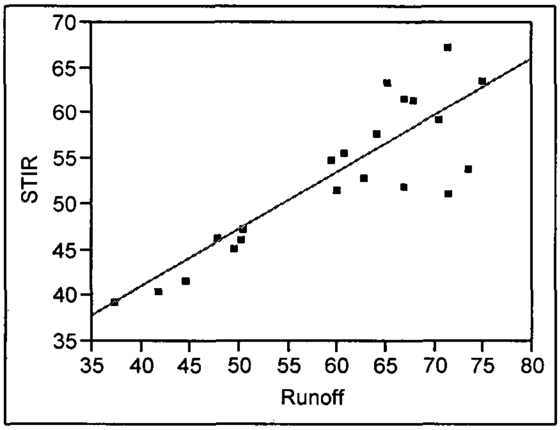
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1174.1488	1174.15	136.0896
Error	14	120.7887	8.63	**Prob > F**
C. Total	15	1294.9375		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.4593616	4.672271	0.53	0.6069
Slope	0.8915634	0.076426	11.67	<.0001*

Bivariate Fit of STIR By Runoff (Summer)



Linear Fit: STIR = 16.080377 + 0.6261935*Runoff

Summary of Fit	
RSquare	0.748607
RSquare Adj	0.735376
Root Mean Square Error	4.170378
Mean of Response	53.54762
Observations (or Sum Wgts)	21

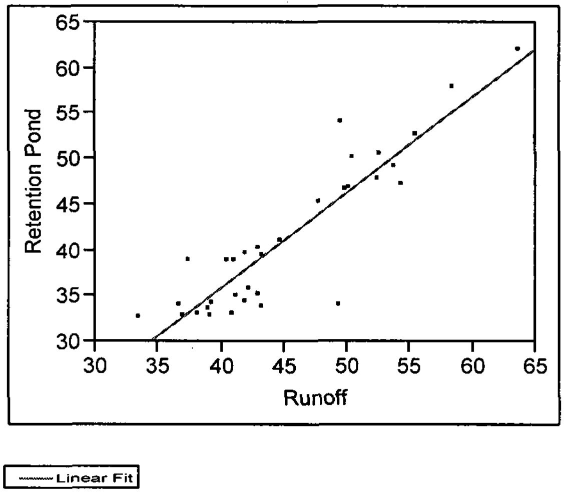
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	984.0234	984.023	56.5789
Error	19	330.4490	17.392	**Prob > F**
C. Total	20	1314.4724		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	16.080377	5.063542	3.18	0.0050*
Slope	0.6261935	0.083249	7.52	<.0001*

Bivariate Fit of Retention Pond By Runoff (Winter)



Linear Fit: Retention Pond = -6.116877 + 1.0504775*Runoff

Summary of Fit	
RSquare	0.816229
RSquare Adj	0.810301
Root Mean Square Error	3.599096
Mean of Response	41.34242
Observations (or Sum Wgts)	33

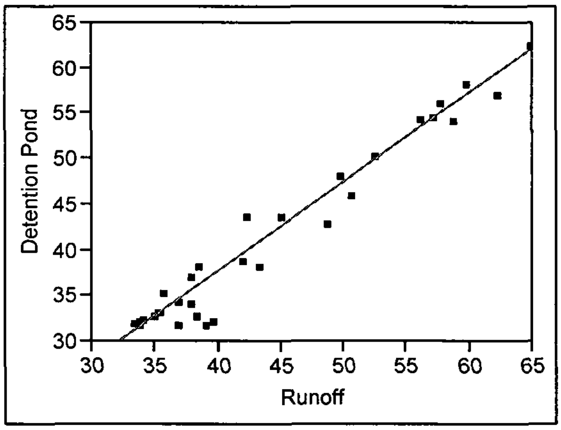
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	1783.5424	1783.54	137.6882
Error	31	401.5582	12.95	**Prob > F**
C. Total	32	2185.1006		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-6.116877	4.092814	-1.49	0.1451
Slope	1.0504775	0.089524	11.73	<.0001*

Bivariate Fit of Detention Pond By Runoff (Winter)



Linear Fit: Detention Pond = -1.467563 + 0.9810386*Runoff

Summary of Fit	
RSquare	0.956849
RSquare Adj	0.955361
Root Mean Square Error	2.090773
Mean of Response	41.93548
Observations (or Sum Wgts)	31

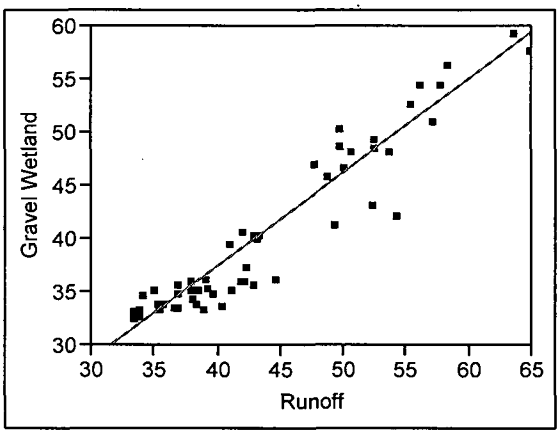
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2811.0424	2811.04	643.0633
Error	29	126.7686	4.37	**Prob > F**
C. Total	30	2937.8110		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.467563	1.752274	-0.84	0.4092
Slope	0.9810386	0.038686	25.36	<.0001*

Bivariate Fit of Gravel Wetland By Runoff (Winter)



Linear Fit: Gravel Wetland = 2.19138 + 0.8828414*Runoff

Summary of Fit	
RSquare	0.903066
RSquare Adj	0.901202
Root Mean Square Error	2.424819
Mean of Response	41.0037
Observations (or Sum Wgts)	54

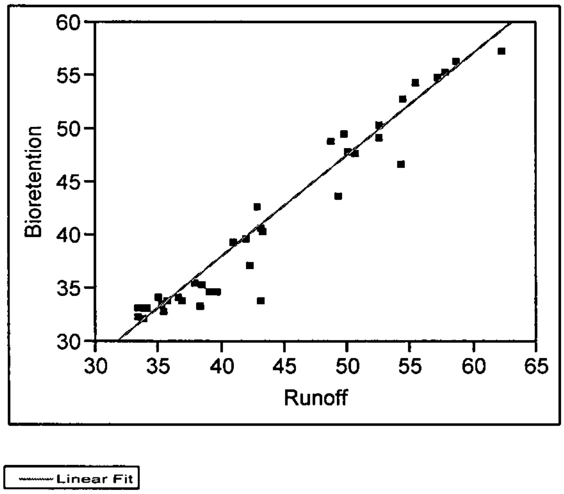
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2848.4325	2848.43	484.4483
Error	52	305.7467	5.88	**Prob > F**
C. Total	53	3154.1793		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	2.19138	1.793988	1.22	0.2274
Slope	0.8828414	0.040111	22.01	<.0001*

Bivariate Fit of Bioretention By Runoff (Winter)



Linear Fit: Bioretention = -0.32904 + 0.9578798*Runoff

Summary of Fit	
RSquare	0.945722
RSquare Adj	0.944255
Root Mean Square Error	1.974744
Mean of Response	41.46154
Observations (or Sum Wgts)	39

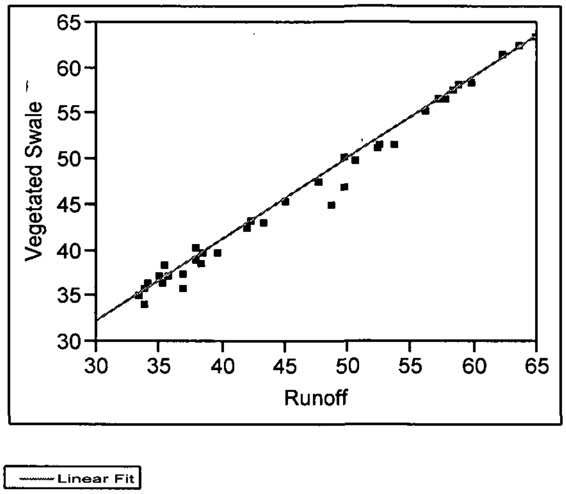
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2513.9866	2513.99	644.6757
Error	37	144.2857	3.90	**Prob > F**
C. Total	38	2658.2723		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.32904	1.676016	-0.20	0.8454
Slope	0.9578798	0.037726	25.39	<.0001*

Bivariate Fit of Vegetated Swale By Runoff (Winter)



Linear Fit: Vegetated Swale = 5.4855815 + 0.8943165*Runoff

Summary of Fit	
RSquare	0.986289
RSquare Adj	0.985886
Root Mean Square Error	1.075783
Mean of Response	46.66389
Observations (or Sum Wgts)	36

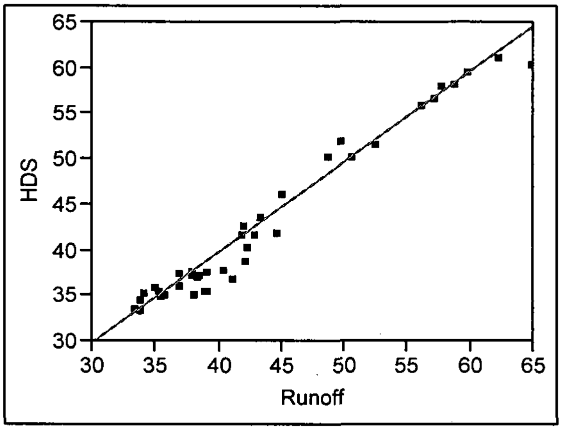
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2830.5545	2830.55	2445.805
Error	34	39.3485	1.16	**Prob > F**
C. Total	35	2869.9031		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	5.4855815	0.851726	6.44	<.0001*
Slope	0.8943165	0.018083	49.46	<.0001*

Bivariate Fit of HDS By Runoff (Winter)



Linear Fit

Linear Fit: HDS = 0.2275004 + 0.9894911*Runoff

Summary of Fit	
RSquare	0.967789
RSquare Adj	0.966919
Root Mean Square Error	1.629708
Mean of Response	43.37692
Observations (or Sum Wgts)	39

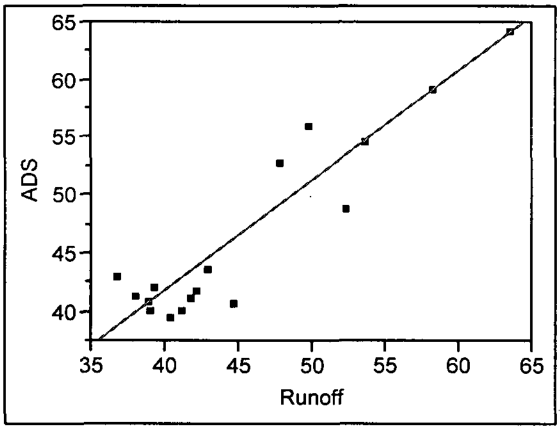
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2952.5592	2952.56	1111.678
Error	37	98.2700	2.66	**Prob > F**
C. Total	38	3050.8292		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	0.2275004	1.320201	0.17	0.8641
Slope	0.9894911	0.029677	33.34	<.0001*

Bivariate Fit of ADS By Runoff (Winter)



Linear Fit

Linear Fit: ADS = 4.0369877 + 0.9469687*Runoff

Summary of Fit	
RSquare	0.863447
RSquare Adj	0.854343
Root Mean Square Error	3.008071
Mean of Response	46.92353
Observations (or Sum Wgts)	17

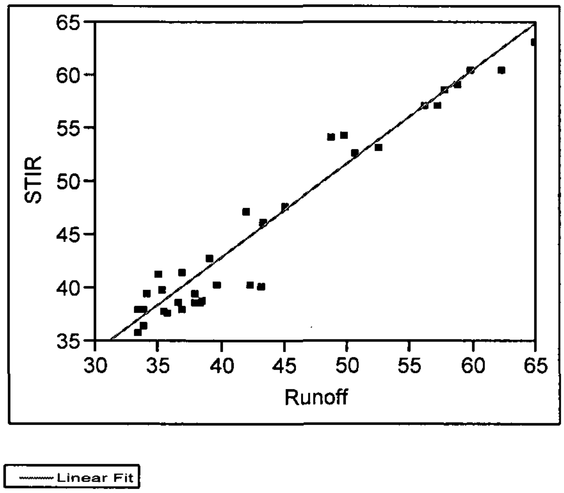
Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	858.22326	858.223	94.8471
Error	15	135.72733	9.048	**Prob > F**
C. Total	16	993.95059		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	4.0369877	4.463636	0.90	0.3801
Slope	0.9469687	0.097235	9.74	<.0001*

Bivariate Fit of STIR By Runoff (Winter)



Linear Fit: STIR = 7.6352601 + 0.8830669*Runoff

Summary of Fit	
RSquare	0.946079
RSquare Adj	0.944394
Root Mean Square Error	2.070518
Mean of Response	46.19412
Observations (or Sum Wgts)	34

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	2407.0134	2407.01	561.4624
Error	32	137.1854	4.29	**Prob > F**
C. Total	33	2544.1988		<.0001*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	7.6352601	1.665578	4.58	<.0001*
Slope	0.8830669	0.037268	23.70	<.0001*

APPENDIX I

CALCULATION OF AN EVENT MEAN TEMPERATURE

Calculating an Event Mean Temperature for a Single Storm

The event mean temperature is congruous to the event mean concentration calculated for other stormwater pollutants. To calculate this metric each storm is separated from the database with the data for the time, flow, and temperature. The data is compiled into 5-minute intervals, so for each 5-minute interval, a volume, and a volume-temperature value was calculated.

The Volume Equation below is the method used to calculate the 5-minute volume values. It is the value of the following time stamp subtracted by the value of the current time stamp, multiplied by the correction value of 1,440 minutes per day to convert the time into the correct unit of minutes. That is then multiplied by the average of the two corresponding flow values of the time stamps. This process is repeated for the entirety of the storm duration, and then the values are summed together for a total storm volume.

The 5-minute volume-temperature value is calculated by multiplying the 5-minute volume value with the average of the 5-minute temperature values. This again, is done for the entirety of the storm duration and the values summed together for a total storm volume-temperature value.

Then using the total volume value, and the total volume-temperature value, an EMT is calculated using the Tabular Equation below. The resulting EMT has units of Fahrenheit, but is now weighted by the flow through the system. Table 1 shows the steps, as they would appear in the data analysis files created to calculate EMTs for each storm.

Table 23: Example Tabular EMT Calculation

Date	Flow	Temperature	Volume	Volume*Temperature
1	11	21		
2	12	22	=1440*(2-1)*[(11+12)/2]	=Volume * [(21+22)/2]
3	13	23	=1440*(3-2)*[(12+13)/2]	=Volume * [(22+23)/2]
4	14	24	=1440*(3-4)*[(13+14)/2]	=Volume * [(23+24)/2]

Graphical Equation:

$$EMT = \frac{\int_{O}^{T} t(t)q(t)dt}{\int_{O}^{T} q(t)dt}$$

EMT = Event Mean Temperature (^{o}F)

T = Flow Duration (min)

t(t) = Flow Temperature (^{o}F)

q(t) = Flow (gpm)

Tabular Equation:

$$EMT = \frac{\sum Vol * Temp}{\sum Vol}$$

EMT = Event Mean Temperature (^{o}F)
Vol = 5-min Flow Volume (gal)
Temp = 5-min Flow Temperature (^{o}F)

Volume Equation:

$$V = 1440 \times (t_{i+1} - t_i) \times \left(\frac{Q_i + Q_{i+1}}{2} \right)$$

V = Flow Volume (gal)
t = time (day)
Q = Flow (gpm)